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The Influence of Actual Working Condition to Electric Poles in the Distribution Network Lines and the Study of the Pole Selection

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The force situation of electrical pole is affected by the actural working condition of distribution network lines including height difference and line angle. By analyzing the influences and introducting a correction coefficient, the selection process of pole would be improved. It could provide enough safety margin to poles and avoid the damage in the case of extreme climate disasters.

1. Introduction

The electric power supply capacity of overhead transmission lines with extensive distribution is large. And the lines are affected by natural disasters seriously. If the lines were damaged, it would decline the stability of the lines. It would also lead to fateful consequence, such as widespread power outages and serious impact on national economy (Fan, 2011). After the ice disaster in 2008, China Southern Power Grid put forward a concept which is called “Abandoning wires to protect poles” in distribution network lines below 35kV when confronted with ice disasters.

Currently, the development of "Abandoning wires to protect poles" project is still in the elementary stage, the programs which are associated with the "abandoning wires to protect poles" project include: the porcelain cross arm adding shearing bolt, the connecting clamp scheme and spring-loaded device to take off the wire. But the programs could not reach the goals. Though in-depth analysis, the reason for the slow progress is the force situation of the pole is very complicated because of the influences from the actual working condition. In recent years, many researchers have made huge progress on the pole-wire load calculation model, the wind tunnel test and filed test. But due to the complicated loading mode, it always lacks of accurate analysis method to guide the design process. So, the collapse and break accidents of poles often happen in typhoon (Eusebi et al., 2017).

2. The influence of the actual working condition to the pole

The force situation of a pole in the actual working condition was analyzed. The actual working condition is shown in the table1.

The point O is the origin of the coordinate and angle bisector line is the Y axis to establish the rectangular coordinate system, as shown in figure 1:

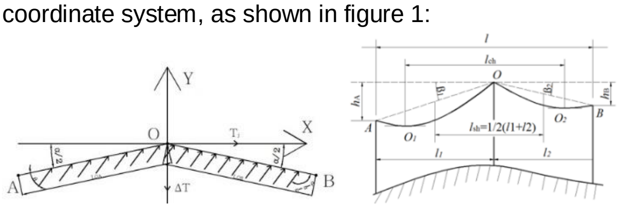

Figure 1: Top view and main view of the line (Wen et al, 2014)

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Table 1: The actual working condition of pole (Xiao et al., 2016)

Line	Span (m)	Corner (°)	Height difference (m)	Angle of height difference (°)	Angle of wind (°)	Wind load ratio (N/(m·mm^2))	Deadweight ratio (N/(m·mm^2))	Cross-section (mm^2)
AO	L_1	α	h_A	β_1	θ	g_4	g	S
OB	L_2		h_B	β_2	$\pi-\theta-\alpha$			

The horizontal load of the Pole O is:

$$P = \sqrt{\left[g_4 S\cos\frac{\alpha}{2}\cdot\left(\frac{l_1\cdot\sin^2\theta}{2\cos\beta_1}+\frac{l_2\cdot\sin^2(\theta+\alpha)}{2\cos\beta_2}\right)-(\sigma_1+\sigma_2)S\cdot\sin\frac{\alpha}{2}\right]^2+\left[g_4 S\sin\frac{\alpha}{2}\cdot\left(\frac{l_1\cdot\sin^2\theta}{2\cos\beta_1}-\frac{l_2\cdot\sin^2(\theta+\alpha)}{2\cos\beta_2}\right)+(\sigma_1-\sigma_2)S\cdot\cos\frac{\alpha}{2}\right]^2} \quad (1)$$

It should be noted that when the wind direction is the same as the angle load direction on the angle bisector line, as shown in figure 2, the horizontal load of the Pole O is line, as shown in figure 2, the horizontal load of the Pole O is

$$P = \sqrt{\left[g_4 S\cos\frac{\alpha}{2}\cdot\left(\frac{l_1\cdot\sin^2\theta}{2\cos\beta_1}+\frac{l_2\cdot\sin^2(\theta+\alpha)}{2\cos\beta_2}\right)+(\sigma_1+\sigma_2)S\cdot\sin\frac{\alpha}{2}\right]^2+\left[g_4 S\sin\frac{\alpha}{2}\cdot\left(\frac{l_1\cdot\sin^2\theta}{2\cos\beta_1}-\frac{l_2\cdot\sin^2(\theta+\alpha)}{2\cos\beta_2}\right)-(\sigma_1-\sigma_2)S\cdot\cos\frac{\alpha}{2}\right]^2} \quad (2)$$

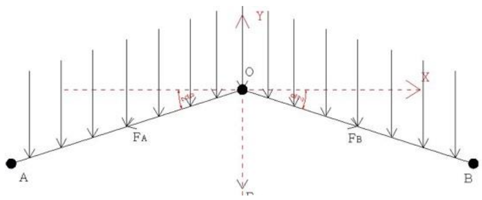

Figure 2: Top view of the line

It is supposed the wind angle is constant, and the line angle changes constantly. As shown in figure 3, when the wind direction is the opposite of the direction of the line angle load, θ=90°, the loads would offset each other. So, if the line angle increases, the horizontal load would decrease. If the line angle load is more than the wind load, the direction of the horizontal load is the same as the line angle load. When the wind direction is the same as the direction of the line angle load, θ=270°, these two loads would be superimposed on each other. So the angle increases, the horizontal load gets larger.

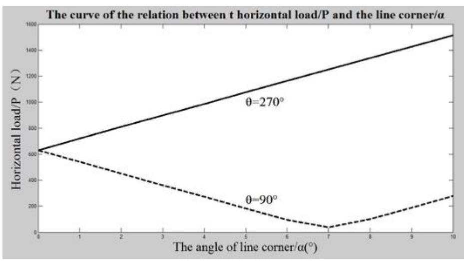

Figure 3: The relationship between wire angle and horizontal force

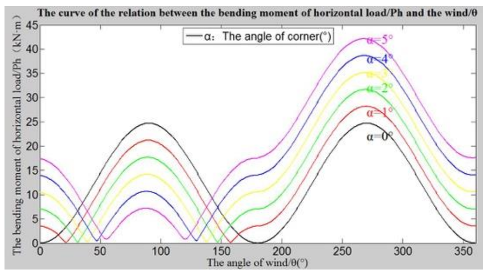

Figure 4: The relationship among wind angle, wire angle and horizontal force

If the line angle is constant, the wind angle changes constantly. As shown in Figure4, the influence of wind angle: when the range of wind angle is 0°~180°, the horizontal load increases initially and decreases afterwards. When the range is 180°~360°, the trend keeps consistent, but the maximum is much bigger than that between 0°~180°. Because the wind direction is the opposite of the direction of the line angle load, the loads would offset each other. When the wind angle is over180°, the two directions are the same, and the two loads would be superimposed on each other.

The vertical load of the pole O is:

$$G = g\cdot S\cdot\left[\frac{1}{2}\left(\frac{l_1}{\cos\beta_1}+\frac{l_2}{\cos\beta_2}\right)+\frac{\sigma}{g}\cdot\left(\pm\frac{h_A}{l_1}\pm\frac{h_B}{l_2}\right)\right]; \quad (3)$$

The selection principle of plus or minus sign in the brackets is: compared with the wire suspension point of the calculated tower, it takes plus sign if the points of two sides is lower, otherwise it takes minus sign (Mao, 2007). The relation between the vertical load and height difference is shown as Figure 5, when h_A and h_B are positive, the load increases with the increase of height difference. Because the vertical load is:

$$G = g \cdot S \cdot \left[\frac{1}{2} \left(\frac{l_1}{\cos\beta_1} + \frac{l_2}{\cos\beta_2} \right) + \frac{\sigma}{g} \cdot \left(+ \frac{h_A}{l_1} + \frac{h_B}{l_2} \right) \right] \tag{4}$$

The direction is vertical downward. The height differences of both sides would be superimposed on each other. When one of height differences is positive, the other is negative, the vertical load is:

$$G = g \cdot S \cdot \left[\frac{1}{2} \left(\frac{l_1}{\cos\beta_1} + \frac{l_2}{\cos\beta_2} \right) + \frac{\sigma}{g} \cdot \left(+ \frac{h_A}{l_1} - \frac{h_B}{l_2} \right) \right] \tag{5}$$

The load remains unchanged, its direction is vertical downward, the height differences of both sides would offset each other.
When the height differences of both sides are negative, the vertical load is:

$$G = g \cdot S \cdot \left[\frac{1}{2} \left(\frac{l_1}{\cos\beta_1} + \frac{l_2}{\cos\beta_2} \right) + \frac{\sigma}{g} \cdot \left(- \frac{h_A}{l_1} - \frac{h_B}{l_2} \right) \right] \tag{6}$$

In the beginning, the direction is vertical downward, the load decreases with the increase of the height differences, and when the value of load is 0, if the height differences still increase, the load starts to increase, its direction is vertical upward.

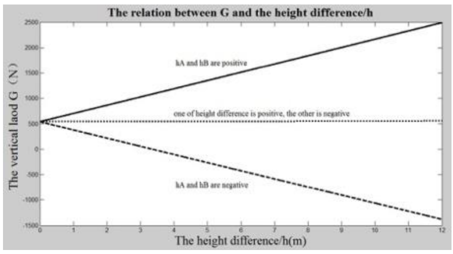

Figure 5: The relationship between height difference and vertical force

The force of suspension point in the Pole O is:

$$F = \sqrt{G^2 + P^2} \tag{7}$$

The table 2 is the force situation of the pole in different working conditions when the type of wire is JL/G1A-185/25, the wind speed is 35m/s and the span of both sides is 50m.

Table 2: Force of the pole in different working conditions of wire type JL/G1A-185/25

No.	h_A (m)	h_B (m)	αα (°)	θ (°)	G(N)	P(N)	F(N)
1	0	0	0	270	345.989	557.107	655.802
2	3	3	0	270	1078.262	557.107	1213.680
3	3	3	1	270	1078.262	758.717	1318.446
4	3	3	2	270	1078.262	960.117	1443.771
5	3	3	3	270	1078.262	1161.283	1584.685
6	3	3	4	270	1078.262	1362.197	1737.305
7	3	3	5	270	1078.262	1562.842	1898.717
8	3	-3	0	270	346.611	557.108	656.132
9	6	-6	0	270	348.471	557.108	657.116
10	6	6	0	270	1811.774	557.108	1895.493

As shown in Table 2, the horizontal load is mainly affected by line corner, and the vertical load is influenced by height difference. According to the data in table2, the range of line corner should be 0°~5°, the height difference should be limited within 3m.

3. The selection process of pole

Currently, the main method to choose a pole is: calculating the maximum of bending moment, and determining the allowed bending moment, then selecting the suitable rank of pole. In principle, its corresponding cracking test bending moment of pole should be higher than the maximum of bending moment.

(1) The determination of the maximum bending moment

As shown in Figure6, according to engineering design of 10kV distribution network line, the line adopts double circuit erection and uses reinforced concrete pole.

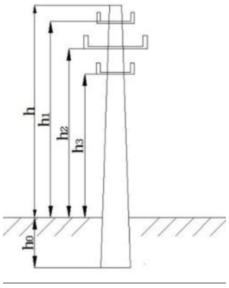

Figure 6: Engineering design of pole

It is assumed that the build-in point of the pole is in 1/3 place under the ground, in this point, the maximum of bending moment would be coming into being, under the action of horizontal load.

$$M = 2W_X\left(h_1 + \frac{h_0}{3}\right) + 2W_X\left(h_2 + \frac{h_0}{3}\right) + 2W_X\left(h_3 + \frac{h_0}{3}\right) + W_S\left(\frac{h}{2} + \frac{h_0}{3}\right) \tag{8}$$

M, the maximum of bending moment of pole, kN·m; W_x W_x, the wind load of wire, N; W_s W_x, the wind load of pole, N; h_1, h_2, h_4, the height of the cross arm, m; h_0, the embedded depth of pole, m; h, the height of the pole on the ground, m.

Considering the additional bending moment from vertical load and the deflection of pole,

$$M_x = 1.15M \tag{9}$$

(2) The determination of the allowed bending moment

The allowed bending moment should be higher than the maximum of the bending moment of the pole, and the certain safety margin should be kept (Li, 2011).

$$M_x \le \beta_u M_k / K \tag{10}$$

$$M_k \ge KM_x / \beta_u \tag{11}$$

M_x, the maximum of bending moment of pole, kN m; β_u, the comprehensive inspection coefficient of pole bearing capacity (the value is 2.0); M_k, the cracking test bending moment, kN m; K, the strength safety coefficient of reinforced concrete flexural members (the value is 1.7)

4. The introduction of a correction coefficient

In general, the pole selection depends on bending moment calculation of the pole in theoretical working condition. However, because of the influences of actual working condition, the actual maximum bending moment is larger than theoretical value. Although a certain safety margin would be kept in the selection, in some working condition, the bending moment is beyond the permissible value of pole. In typhoon weather, the safety margin could not meet the requirement against typhoon. It would lead to some poles are damaged in typhoon weather. In order to ensure the power supply and the safety of electric power grid, and reduce the cost to preserve the life of the power grid, meanwhile, avoid increasing over investment of general improvement of the design standard, the important measure to improve the ability against typhoon of the overall power grid is the design differentiation of different lines or different district in the same line (Wu, 2015).

The actual working condition would be considered in calculation of maximum bending moment and the pole selection by introducing a correction coefficient. The advantages of this method include the consideration to actual working condition and the simplification of calculation, and it can provide enough safety margin to all kinds of poles when facing typhoon weather.

The method is:

$$M = \alpha \cdot M' + W_s\left(\frac{h}{2} + \frac{h_0}{3}\right) \tag{12}$$

$$M' = 2W_x\left(h_1 + \frac{h_0}{3}\right) + 2W_x\left(h_2 + \frac{h_0}{3}\right) + 2W_x\left(h_3 + \frac{h_0}{3}\right) \tag{13}$$

M, the maximum of bending moment of pole, kN m; α, the correction coefficient of line corner; M', the bending moment from wind load, kN m; W_x, W_x the wind load of wire, N; W_S W_x, the wind load of pole, N; h_1, h_2, h_3, the height of the cross arm, m; h_0, the embedded depth of pole, m; h, the height of the pole on the ground, m.

Table 3 is the value of α of several kinds of wires in the working condition (wind speed is 35m/s, span of two sides is 50m). The Table3 can be referred in the design process to adjust the value of α, according to the actual working condition.

Table 4: The α value of different wire types between 1°~5°

Wire Type	Line Corner (°) 0	1	2	3	4	5
	α					
JL/G1A-185/25	1.00	1.36	1.72	2.08	2.45	2.81
JL/G1A-50/8	1.00	1.24	1.48	1.71	1.95	2.19
JL/G1A-70/10	1.00	1.27	1.54	1.80	2.07	2.34
JL/G1A-95/15	1.00	1.31	1.63	1.94	2.25	2.56
JL/G1A-120/20	1.00	1.33	1.65	1.98	2.30	2.63
JL/G1A-150/25	1.00	1.37	1.74	2.11	2.48	2.84
JL/G1A-240/30	1.00	1.39	1.79	2.18	2.57	2.96
JKLYJ-10/50	1.00	1.11	1.23	1.34	1.45	1.56
JKLYJ-10/70	1.00	1.12	1.25	1.37	1.49	1.61
JKLYJ-10/95	1.00	1.13	1.27	1.40	1.53	1.66
JKLYJ-10/120	1.00	1.13	1.27	1.40	1.53	1.66
JKLYJ-10/150	1.00	1.15	1.29	1.44	1.59	1.73
JKLYJ-10/185	1.00	1.15	1.29	1.44	1.59	1.73
JKLYJ-10/240	1.00	1.17	1.35	1.52	1.70	1.87

If the pole is installed in the working condition shown in Figure7, because of the unilateral working condition, the bending moment from vertical load of the wire could be offset. So, when selecting the pole, the height difference should be considered by introducing the correction coefficient of height difference β.

$$M_y = \beta \cdot M_y' \tag{14}$$

$$M_y' = W_y \cdot a \tag{15}$$

M_y, the actual bending moment from vertical load; β, the correction coefficient of height difference; M_y', the theoretical bending moment from vertical load; W_y, the theoretical vertical load; a, the horizontal distance from the wire suspension point to the pole.

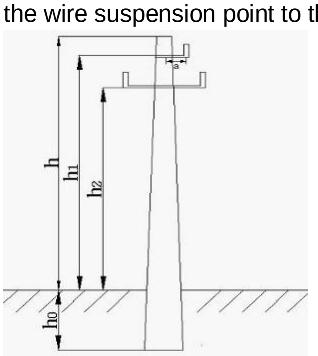

Figure 7: Other pole working condition

The value of β is shown in Table 5.

Table 5: The β value of different wire types between height 0~3m

Wire Type	Height Difference (m) 0 β	1	2	3	Wire Type	Height Difference (m) 0 β	1	2	3
JL/G1A-185/25	1.00	1.71	2.41	3.12	JKLYJ-10/50	1.00	1.25	1.50	1.75
JL/G1A-50/8	1.00	1.52	2.03	2.55	JKLYJ-10/70	1.00	1.27	1.54	1.80
JL/G1A-70/10	1.00	1.55	2.09	2.64	JKLYJ-10/95	1.00	1.28	1.57	1.86
JL/G1A-95/15	1.00	1.65	2.30	2.96	JKLYJ-10/120	1.00	1.30	1.60	1.90
JL/G1A-120/20	1.00	1.67	2.33	3.00	JKLYJ-10/150	1.00	1.31	1.61	1.92
JL/G1A-150/25	1.00	1.73	2.46	3.20	JKLYJ-10/185	1.00	1.33	1.65	1.98
JL/G1A-240/30	1.00	1.74	2.47	3.21	JKLYJ-10/240	1.00	1.35	1.69	2.04

5. Conclusion

In this paper, the influences of the actual working condition to the force situation of the pole were analyzed in depth. In the basis, the complicated force calculation of pole in actual working condition was simplified by introducing a correction coefficient. Finally, the pole selection process got improved, and it could ensure the safety margin is enough to the pole against the weather which is beyond line design condition. It provides new theory and method to the implement of “Abandoning wires to protect poles” project.

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