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An effective method for calculating crossed span distance of overhead line based on three-dimensional inclination algorithm

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Abstract

In order to safely operate the electric transmission lines, to monitoring the crossed span distance of the overhead lines is one of the key measures. Since the current measurement methods of crossed span distance of overhead line has high cost, low accuracy, and traditional measurement methods has low efficiency, the monitoring model of overhead line in three-dimensional space is constructed, and based on oblique parabola equation. The algorithm for detecting the crossed span distance based on three-dimensional inclination under the windless and windy conditions is studied, which are applied to the on-line monitoring system. Through actual measurement, the accuracy and practicability of the three-dimensional model and algorithm are verified which provides reliable algorithm support for traverse crossing distance measurement and on-line monitoring system, and improves work efficiency.

Keywords: overhead line, oblique parabola, three dimensional dip.

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1. Introduction

In order to safely operate the electric transmission lines, to monitoring the crossed span distance of the overhead lines is one of the key measures. Due to the influence of environment and its own running state, the crossed span distance of the overhead lines will change. Discharge, alternating flashover and tripping accidents may occur when the distance is too short [1-4]. In recent years, as the number of overhead lines has increased, the problems caused by crossed span distance have become more apparent. Therefore, the periodic measurement of the crossing distance of overhead line plays a vital role in the operation and maintenance of transmission lines. At present, the research on the crossed span distance monitoring of overhead lines at world mainly includes temperature monitoring [5], tension monitoring [6], image monitoring [7] and Unmanned Aerial Vehicle (UAV) monitoring [8], but they have not been widely used due to the high cost, inconvenient installation or high requirements for equipment. At present, the research on the crossed span distance monitoring of overhead lines at world mainly include temperature monitoring, tension monitoring, image monitoring and Unmanned Aerial Vehicle (UAV) monitoring, but they have not been widely used due to the high cost, inconvenient installation or high requirements for equipment. At present, the method of manual measurement is still adopted, such as the theodolite [9], rangefinder [10-11] and total station [12-13], which requires the surveyor to carry the instrument to the site for measurement. These methods are accurate, but the work is heavy, the operation is tedious, and the measurement data cannot be stored and analysed in real time. Therefore, it is urgently needed to study the monitoring method of the crossed span distance of overhead lines, which is easy and cheap to operate, and can meet the requirements of accuracy.

Therefore, this paper studies three-dimensional model and algorithm of the crossed span distance of overhead lines, calculates the crossed span distance of overhead lines under windless and windy conditions according to the change of three-dimensional inclination of the lines, and applies it to the online monitoring system to realize the fast and accurate measurement of the crossing distance of overhead lines.

2. Monitoring models and algorithm of line's crossed span distance

2.1. Static oblique parabolic equation

The overhead line is suspended between two towers for power transmission. There are three equations to indicate the suspension status: the catenary equation, the oblique parabolic equation and the parabolic equation [15]. As for the catenary equation, it provides the highest accuracy [16], but the calculation is too complicated. On the other hand, the parabolic equation's deviation is too high to accept. In order to calculate the crossed span distance of the overhead line accurately, the authors adopted the oblique parabolic equation to set up a three-dimensional model.

Figure 1 shows the oblique parabolic model of the overhead line, and the equation of the oblique parabolic is:

$$y(x) = \frac{x^2}{2M\cos\theta}. \tag{1}$$

Where x is x-axis coordinates of any point on the curve. According to Figure 1, $\theta = tan^{-1} -$, where h and l are the height difference, and the distance between two towers, respectively, and $M = -$, where σ and g are horizontal stress at the lowest point of the line, and gravity specific load.

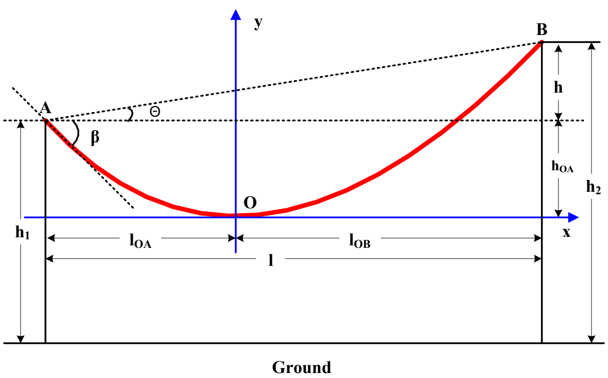

Figure 1. The diagrammatic sketch of oblique parabolic

For the convenience of calculation, the coordinate origin (O) is moved to the low suspension point (A), so that the equation of the oblique parabolic [17] becomes:

$$y(x) = \frac{(x-l_{OA})^2}{2M\cos\theta} - h_{OA}. \tag{2}$$

Where is the vertical distance between the lowest point of the line (O) and the suspension point(A),

As shown in Figure 1,$l_{OA}+l_{OB}=l$, $y(l_{OB})-y(-l_{OA})=h$, combining them with equation (1), a new equation is derived:

$$\begin{cases} l_{OA} = \frac{l}{2} - M\sin\theta \\ l_{OB} = \frac{l}{2} - M\cos\theta \\ y_1'(-l_{OA}) = \frac{l_{OA}}{M\cos\theta} = \tan\beta \end{cases}. \tag{3}$$

If A is set as the low suspension point and β is set as A's vertical inclination angle, M and l_{OA} can be derived from equation (3):

$$\begin{cases} M = \frac{l}{2(\sin\theta+\cos\theta\tan\beta)} \\ l_{OA} = \frac{l}{2} - \frac{l\cos\theta}{2(\sin\theta+\cos\theta\tan\beta)} \end{cases}. \tag{4}$$

The oblique parabolic equation is derived by substituting equation (2) with equation (4).

2.2 Three-dimensional model and algorithm of crossed span distance under windless condition

The crossed span distance between the static line and the object

When the line crosses the object, the crossed span distance is the difference between the line's altitude and the object's height. The height of the object is supposed as H_0, the crossed span distance between the line and the object can be derived as below from equation (2):

$$G(x) = h_1 + \frac{(x-l_{OA})^2}{2M\cos\theta} - h_{OA} - H_0. \tag{5}$$

The crossed span distance of two static lines

The following space model shows the crossed span of two static lines, as illustrated in Figure 2.

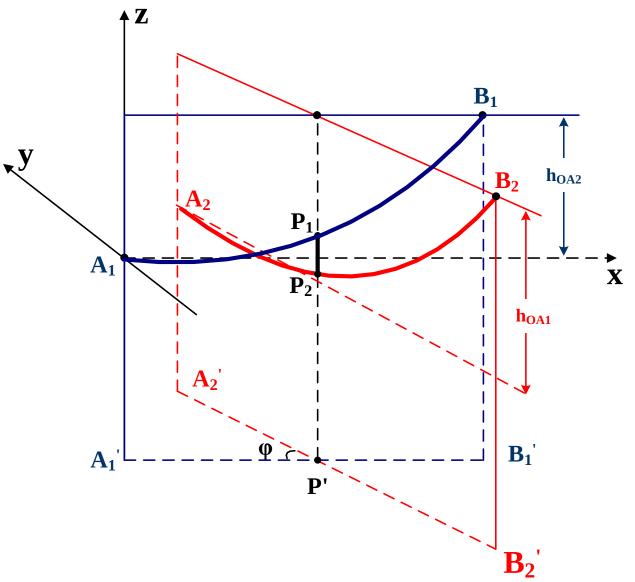

Figure 2. The diagrammatic sketch of crossed span under windless condition

The arc $A_2P_2B_2$ passes below $A_1P_1B_1$, P_1 and P_2 are the crossing points, P' is the projection of P_1P_2 to the ground, |P1P2| is the crossing span distance. $A_1'B_1'$ and $A_2'B_2'$ are the projections of $A_1P_1B_1$ and $A_2P_2B_2$, respectively, with an angle of φ. Taking A as the origin and establishing a three-dimensional Cartesian coordinate system, $A_1P_1B_1$ can be calculated as:

$$\begin{cases} z = \frac{1}{2M_1\cos\theta_1}(x - l_{OA1})^2 - h_{OA1} \\ y = 0 \end{cases} \quad (6)$$

A_2 is set as coordination (x_2, y_2, z_2), then the equation of $A_2P_2B_2$ can be translated by $A_1P_1B_1$ around the *z*-axis (rotation angle φ), the equation is:

$$z = \frac{[(x-x_2)\cos\varphi-(y-y_2)\sin\varphi-l_{OA2}]^2}{2M_2\cos\theta_2} - h_{OA2} \quad (7)$$
$$y = y_2 - (x - x_2)\tan\varphi$$

The horizontal plane coordinate of the projection point P' is ($y_2\cot\varphi +$). Substituting equations (6) and (7) one can obtain the z-axis coordinate and further calculate the cross-over distance:

$$|P_1P_2| = \left| \frac{(y_2\cot\varphi+x_2-l_{OA1})^2}{2M_1\cos\theta_1} - \frac{[y_2(\cot\alpha\cos\alpha+\sin\alpha)-l_{OA2}]^2}{2M_2\cos\theta_2} - (h_{OA1} - h_{OA2}) - z_2 \right|. \quad (8)$$

In equation (8), M and M are load ratios; θ and θ are elevation angles; and are vertical distances from the lowest point to the lowest suspension point; The and from the lowest point to the lowest point of suspension point, can be obtained from equations (2) and (4) .

2.3 Three-dimensional model and algorithm of crossed span distance under wind condition

The crossed span distance between the swinging line and the object

Line swinging is one of the main reasons for line breakage and tower tilting [18]. Under the action of wind, the line swings in a certain range. The three-dimensional model of the line under wind condition is shown in Figure 3.

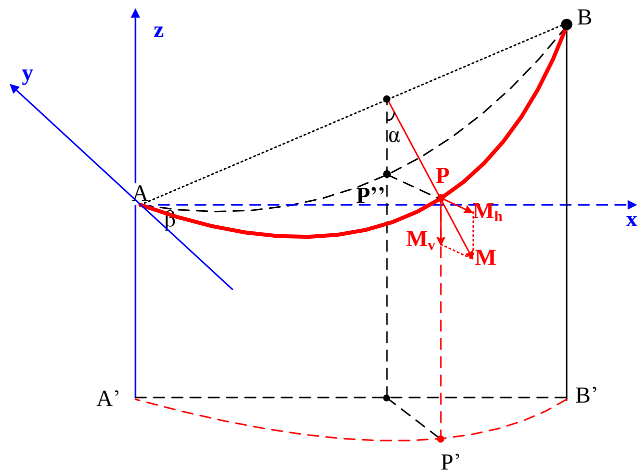

Figure 3. The diagrammatic sketch of the line under wind condition

Curve APB is the state when the line is swinging, the dotted line AP"B is the projection of APB in the vertical plane (xoz plane), which can be approximated as the static state curve of the line, and A'P'B' is the projection of the line APB on the horizontal plane. If setting it as a parabolic contour, α is the horizontal dip (also called the yaw angle), based on force analysis:

$$\tan\alpha = \frac{M_h}{M_v}. \quad (9)$$

Where M_h,M_v are the vertical and horizontal load ratios, respectively, $M_v \approx M$, $M_h = M_v\tan\alpha$, the horizontal tilt angle α can be measured by the tilt sensor.

When the wind drifts, the expression of line APB is:

$$\begin{cases} z = \frac{1}{2M_v \cos\theta}(x - l_{OA})^2 - h_{OA} \\ y = \frac{1}{2M_h \cos\theta}\left[\left(x - \frac{l}{2}\right)^2 - \frac{l^2}{4}\right] \end{cases} \quad (10)$$

At this time, the height of the line to the ground is only related to the projection AE’’B of the line AEB in the vertical plane, so the distance between any point of the line and the fixed object is:

$$H(x) = h_1 + \frac{(x - l_{OA})^2}{2M_v \cos\theta} - h_{OA} - \mathrm{H}_0. \quad (11)$$

The crossed span distance of two swinging lines

The crossed span distance model under the swinging state is shown in Figure 4. At this time, the projections of the two crossed lines on the horizontal plane are $A_1'P'B_1'$ and , respectively. The expression of line $A_1P_1B_1$ is obtained from equation (10):

$$\begin{cases} z = \frac{1}{2M_{1v} \cos\theta_1}(x - l_{OA1})^2 - h_{OA1} \\ y = \frac{1}{2M_{1h} \cos\theta_1}\left[\left(x - \frac{l_1}{2}\right)^2 - \frac{l_1^2}{4}\right] \end{cases} \quad (12)$$

The equation (12) is transformed by polar coordinates and inverse transformation to obtain the expression of line $A_2P_2B_2$:

$$\begin{cases} z = \frac{1}{2M_{2v} \cos\theta_2}(x\cos\varphi - y\sin\varphi - l_{OA2})^2 + z_2 - h_{OA2} \\ y\cos\varphi + x\sin\varphi = b + \left[\frac{x\cos\varphi - y\sin\varphi - a}{2M_{2h} \cos\theta_2} - c\right]^2 - c \end{cases} \quad (13)$$

Where $a = x_2\cos\varphi - y_2\sin\varphi$, $b = x_2\sin\varphi - y_2\cos\varphi$, and $c = \frac{l_2^2}{8M_{2h}\cos\theta_2}$.

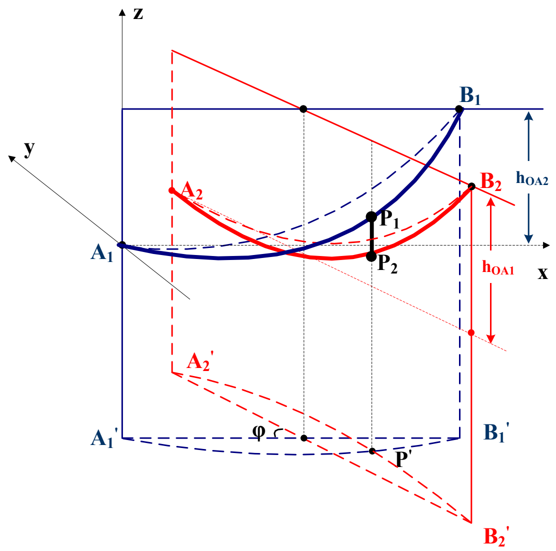

Figure 4. The diagrammatic sketch of crossed span under wind condition

According to the Newton iteration method, from the second equation in equations (12) and (13), the coordinates (x', y') of P' can be obtained and taken into the first equation, then the *z* value can be obtained. At last, the crossed span distance of two power transmission lines under the wind deflection is calculated: $|P_1P_2| = |z_1 - z_2|$, where z_1 and z_2 are the z-axis coordinates of the points P_1 and P_2, respectively.

3. Model and algorithm application

The model and algorithm have been applied to the real-time monitoring system of overhead traverse crossing distance, and have been tested and verified on a number of 220kv lines of State Grid Fushun Power Supply Company. The artificial measurement values in the windless and windy states were compared with the measured values of the system, as shown in Table 1. This measurement result is close to the measurement result of the traditional method (total station), and the measurement error under windy condition is slightly larger than that under windless condition.

Table 1. Comparison between manual and system measurements

Monitoring point	Crossing objects	State	Vertical inclination β(°)	Horizontal inclination α(°)	Manual measured values (m)	System measured values (m)	Discrepancy (%)
1	Motorway	Windless	15	0	6.52	6.45	1.07
1	Motorway	Windy	15	10	7.18	7.03	2.09
2	Railway	Windless	10	0	5.75	5.69	1.04
2	Railway	Windy	10	8	6.34	6.22	1.89
3	House	Windless	8	0	7.55	7.48	0.93

3	House	Windy	8	12	7.89	7.75	1.77
4	Highway	Windless	12	0	4.97	4.9	1.41
4	Highway	Windy	12	9	5.23	5.13	1.91
5	Overhead line	Windless	18	0	8.51	8.43	0.94
5	Overhead line	Windy	18	10	8.90	8.75	1.69

In order to more intuitively represent the state of the lines, Matlab tool was used to simulate the state of the two crossing lines at monitoring point 5 in real time. In line 1, the span between two towers is 300m, height difference between two towers is 10.7m, the distance from the intersection to the low suspension point is 88 m, horizontal inclination Angle is 10 degrees, and vertical inclination Angle is 18 degrees. In line 2, the span between two towers is 250m, height difference between two towers is 6.2m, the distance from the intersection to the low suspension point is 115m, the horizontal inclination Angle is 8 degrees, and vertical inclination Angle is 15 degrees. The intersection angle of the two lines is 86.5 degrees. According to the above three-dimensional model, the curves of overhead lines at windless and windy condition are drawn, as shown in Figure 5 and Figure 6.

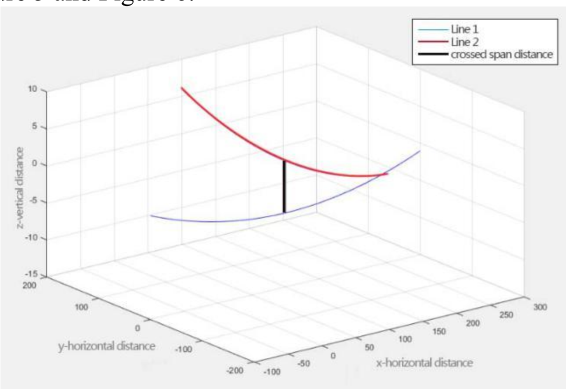

Figure 5. Simulation under windless condition

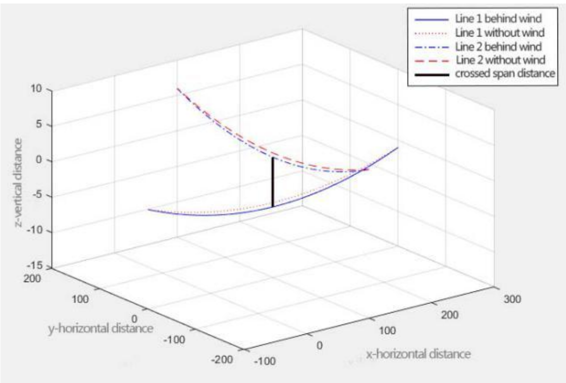

Figure 6. Simulation under wind condition

The dynamic change of lines can be seen intuitively through the graph. According to the span, height difference, the distance from the intersection to the low suspension point, the horizontal inclination Angle, the vertical inclination Angle, etc., the crossed span distance is calculated, and the state of overhead lines is monitored in real time. The electric power department only needs to collect the inclination data through the real-time monitoring device, and obtain the real-time status data of the wire by using the three-dimensional model and algorithm, and conduct circuit inspection and maintenance based on the data, so as to ensure the safe operation of the line. It is a very effective monitoring method.

4. Conclusion

In this paper, the crossed span distance of the overhead lines under the windless and wind bias conditions was studied and a three-dimensional of the overhead line's crossed span model which was applied to the online monitoring system, was established. The result showed that the monitoring system applied the model could replace the traditional manual measurement and the crossed span distance of the overhead lines was calculated more timely and accurately so as to reduce the manual measurement workload greatly. The power department can carry out inspection and maintenance of the line according to the monitoring result, which decreases the operation cost significantly and ensures the safe and stable operation of the transmission lines. As a result, the model provides the technical support for the construction of the smart grid.

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