

Mechanics Analysis of Overhead Transmission Lines Based On-line Monitoring

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ABSTRACT

At present, the on-line monitoring is widely applied to the power line monitoring. In this paper, a new mechanical calculation model is established according to the on-line monitoring. And this model is based on the parameters that tension sensors and angle sensors on suspended points detect, and combines with the parameters of the wire itself, and also considers the deflection angel of wires due to wind. In this model, mechanics parameters of wires are turned into the new coordinate plane after deflection angel of wires due to wind, or windage yaw plane. A statics tension balance equation is built in the vertical direction of the new windage yaw plane. According to the theoretical analysis and algorithm, we verify the accuracy of this newly developed mechanical calculation model.

Keywords: Overhead Transmission Line; On-line Monitoring; Mechanical Analysis; Tension; Angle; Icing; Windage Yaw

1. Introduction

Affected by climate, macrophotography and meteorological conditions, icing of transmission line occurs widely in China and causes ice disasters accident such as short terms, pour towers [1]. For example, in January 2008, parts of Southern China suffered a rare sleet weather resulting in widespread icing of transmission lines, and ice thickness of some towers obviously went beyond line mechanical carrying capacity. The heavy ice cover even caused the collapse of towers, which not only strongly affected and threatened the safety and stability of the power grids but also caused huge economic loss[2].

In on-line monitoring systems, tension sensors and angle sensors are the bare essentials. Tension and angle of suspended points can reflect the role of the wind on conductors and the changes of conductors state. This paper detects the steady state icing of overhead power lines mainly through the combination of axial tension, deflection angel and swing angle of suspension point.

2. Static Mechanics Analysis Model of the Straight Tower

In engineering calculations, they often overlook the rigidity of overhead conductors as flexible cable. And in fact, we assume that the wire load is evenly distributed along the deflection span, for the reason that the difference between the arc length of the wire and the distance of the two suspension points in a span is very small. For the

above reasons, the inclined parabola formulas can be applied in the calculation of the wires, and the error is within the allowable range in the engineering.[3]

2.1. Statics Mechanics Analysis in the Vertical Plane

The mechanical model of the overhead transmission lines in the condition of no wind and no ice is in **Figure 1**. Shown in the **Figure 1**, l is the span length; h is the height difference between the two neighboring towers; β is the angle of height difference between the two neighboring suspension points; l_v is the distance between the lowest points and the main tower; γ is the load of the wire itself.

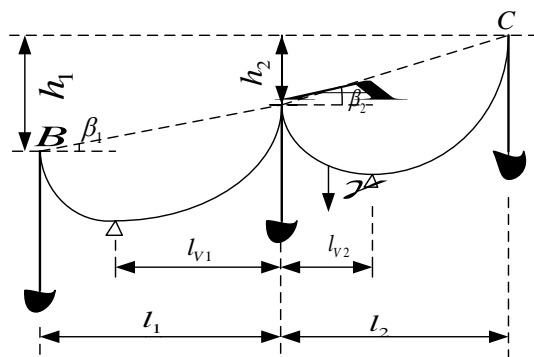


Figure 1. Transmission line model without external load in vertical plane of towers.

By the horizontal force balance condition, we know that the horizontal component of each point tension are equal to the stress σ_o of the lowest point. So

$$F \cdot \cos \theta = \sigma_o A, \quad (1)$$

where F is the tension of the suspension points; θ is the deflection angle of the suspended points; A is sectional area.

We have known F , θ and A , so we can calculate σ_o through the equation(1).

1) the original length S of wires in a span[3]

$$S = \frac{l}{\cos \beta} + \frac{\gamma^2 l^3 \cos \beta}{24 \sigma_o^2} \quad (2)$$

2) the distance l_v between the lowest points and the main tower[3]

$$l_{v1} = \frac{l_1}{2} + \frac{\sigma_o h_1}{\gamma l_1} \quad (3)$$

$$l_{v2} = \frac{l_2}{2} - \frac{\sigma_o h_2}{\gamma l_2} \quad (4)$$

3) the wire length S_v between the lowest points and the main tower[4]

$$S_{v1} = l_{v1} + \frac{\gamma^2 l_{v1}^3}{6 \sigma_o^2 \cos^2 \beta_1} \quad (5)$$

$$S_{v2} = l_{v2} + \frac{\gamma^2 l_{v2}^3}{6 \sigma_o^2 \cos^2 \beta_2} \quad (6)$$

2.2. The Mechanics Analysis in Windage Yaw Plane

In engineering calculation, the wire length is approximately equal to the inclined span length, so the angle between the wind and the wire can be treated as the angle between the wind and the inclined span approximately. Under this assumption, and by the effect of wind, the overhead transmission lines must lie in the plane formed by the line of the comprehensive load action.[3]

In the existing model, the mechanical calculation of the icing wires is only in the vertical plane without considering the influence of wind. But the tension sensors can only detect the magnitude of force and can't measure the direction. In fact, the tension is not fixed in the vertical plane, and it will change as the change of the deflection of the wires due to the wind. In this paper, the mechanical analysis is in the new coordinate plane due to wind.

As is shown in **Figure 2**, the parameters' relation of the vertical plane and the windage yaw plane is this[3]:

$$l' = l \sqrt{1 + (\tan \beta \sin \eta)^2} \quad (7)$$

$$h' = h \cos \eta \quad (8)$$

$$\sigma'_o = \sigma_o \sqrt{1 + (\tan \beta \sin \eta)^2} \quad (9)$$

$$\cos \beta' = \cos \beta \sqrt{1 + (\tan \beta \sin \eta)^2} \quad (10)$$

$$\sin \beta' = \sin \beta \cos \eta \quad (11)$$

$$\sigma'_A = \frac{\sigma_o}{\cos \beta} + \gamma' \left(\frac{\gamma' l^2}{8 \sigma_o \cos \beta} - \frac{h \cos \eta}{2} \right) \quad (12)$$

$$\sigma'_B = \frac{\sigma_o}{\cos \beta} + \gamma' \left(\frac{\gamma' l^2}{8 \sigma_o \cos \beta} + \frac{h \cos \eta}{2} \right) \quad (13)$$

where l' is the span; h' is the height difference; β' is the angle of height difference; σ'_A is the horizontal stress; σ'_A , σ'_B is respectively the tension of the suspended points A and B . What's more, all the above parameters are in the windage yaw plane. And σ_o is the horizontal stress in the vertical projective plane, and η is the windage yaw angle.

Angle sensors usually detect the deflection angle of the suspended points in the vertical plane. And the equation (14) is shown: [3]

$$\tan \theta_{vA} = \tan \beta + \gamma_v l / (2 \sigma_o \cos \beta) \quad (14)$$

The relationship between the vertical comprehensive load γ' in windage yaw plane and the vertical load γ_v is that:

$$\gamma' = \gamma_v / \cos \eta \quad (15)$$

Take advantage of the wire axial tension F of the point A measured by the tension sensor, windage yaw angle η measured by the angle sensor and the deflection angle θ_{vA} of suspended point A in the vertical plane, we can work out the comprehensive load γ' of the wire and the horizontal tension σ'_o of the wire in vertical plane according to Equations (12)(14)(15).

According to the Equations (2)(5)(6), in the windage yaw plane, the length S' of the wire in a span and the lengths S'_{v1} and S'_{v2} of the wire between the lowest point and the main tower are as follows:

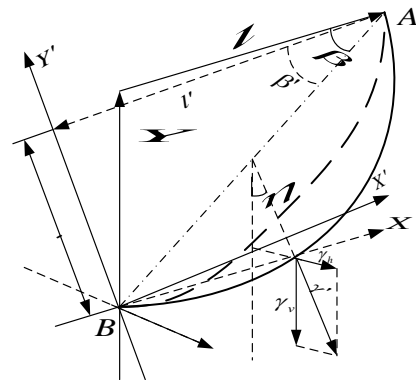


Figure 2. The mechanics analysis of the conductor in windage yaw plane.

$$S' = \frac{l'}{\cos \beta'} + \frac{\gamma'^2 l'^3 \cos \beta'}{24\sigma_o'^2} \quad (16)$$

$$S'_{V1} = l'_{V1} + \frac{\gamma'^2 l'^3_{V1}}{6\sigma_o'^2 \cos \beta_1'^2} \quad (17)$$

$$S'_{V2} = l'_{V2} + \frac{\gamma'^2 l'^3_{V2}}{6\sigma_o'^2 \cos \beta_2'^2} \quad (18)$$

2.3. The Mechanics Analysis of Icing Wires in the New Coordinate Plane Due To Wind

Because of the change of meteorological conditions, the conductor tensions in different spans will change by the parameters of themselves. And it will result that wires of different spans have different horizontal tensions, and the suspended points will occur horizontal movement until the horizontal tensions of the neighbouring spans are equal. The model of the icing wires in the windage yaw plane is shown as **Figure 3**, and the position of insulators and wires is described in **Figure 4**.

In order to simplify the calculation, we assume that the deflection angle of insulator chain is the same to the suspended point's. And considering that the difference of θ' and θ'_A is small, we assume that $\theta' \approx \theta'_A$ and $\theta'_V \approx \theta'_{VA}$.

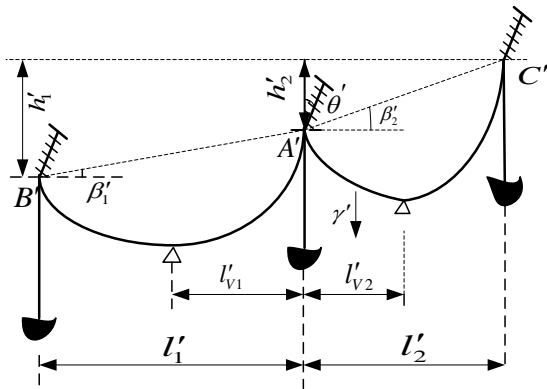


Figure 3. The calculating model of icing wires in the windage yaw plane.

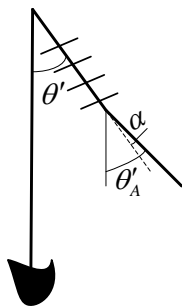


Figure 4. The system of insulator-wire in the new coordinate plane due to wind.

According to the above hypothesis, the deflection angle θ' and the windage yaw angle η and the deflection angle θ_{VA} of the suspended point A in the vertical plane have this relationship[5]:

$$\cos \theta' = 1 / (\cos \eta \sqrt{1 + \tan^2 \eta + \tan^2 \theta_{VA}}) \quad (19)$$

For the suspended point A, the equation about the vertical load γ_V and the vertical component of the tension F_A is shown as:

$$F_A \cos \theta' = [\gamma_V A (S'_{V1} + S'_{V2})] / \cos \eta \quad (20)$$

where γ_V is the comprehensive vertical load of the icing wires, and $\gamma_V = \gamma + \gamma_{ice}$; γ_{ice} is the load of the icing wires.

The equation (20) can deduce the load of icing wire:

$$\gamma_{ice} = \frac{F_A \cos \theta' \cos \eta}{(S'_{V1} + S'_{V2}) A} - \gamma \quad (21)$$

According to the calculation icing load and the shape of icing conductor which is set to a uniform cylindrical by the transmission line design standard of power system, then the calculation formula of icing thickness is as follows:

$$b = 0.5 \left(\sqrt{\frac{4\gamma_{ice} A}{9.8\pi\rho} + d^2} - d \right) \quad (22)$$

where d is the calculation diameter of conductor; b is the icing thickness; ρ is the icing density, and it's usually equal to 0.9 g/m^3 .

3. Demonstration

We will verify the validity of this model by calculating the wind load γ_{wind} of the icing wire [6].

It's called the wind load γ_{wind} of icing wires that icing wires of per meter and per square millimeter withstand wind press load. The expression of γ_{wind} algorithm is as follows:

$$\gamma_{wind} = \frac{0.6125\alpha C(2b+d)v^2}{A} \times 10^{-3} \quad (23)$$

where α is the non-uniform coefficient of wind speed, the values are shown in **Table 1**; v is the design wind speed; C is the figure coefficient of wind load, and it's usually equal to 1.2. If the ratio of γ_{wind} and γ_V is equal to $\tan \eta$, then the model in this paper is validity.

Table 1. The value of α in different conditions

v (m/s)	≤ 20	20~30	30~35	≥ 35
α	1.0	0.85	0.75	0.70

4. Conclusions

In this paper, we just build a model in theory that applicable to the usual on-line monitoring. As for as the accuracy and practicability, practical examples have yet to prove the model. If the model is correct, it will be applicable to the conditions that monitoring systems have not image detection or that the weather is freezing and affects the icing monitoring.

The new model can get icing information, so that we can timely de-icing if the icing is beyond line mechanical carrying capacity and guarantee the normal use of electric transmission wires in the freezing climate.

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