

Study on the calculation method for dynamic wind deflection of transmission line in strong wind area

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Abstract. In order to improve the design and early-warning accuracy for wind deflection of transmission line in strong wind area, it is necessary to calculate the dynamic wind deflection of transmission line in consideration of fluctuating wind effect. In this paper, the generation method for fluctuating wind velocity in consideration of spatial correlation is discussed, then the wind load on every element node of conductor is determined on the basis of the calculation formula for wind load, and finally the dynamic wind deflection angle of insulator and the dynamic wind deflection displacement of conductor is calculated by using the nonlinear dynamic finite element method.

1. Introduction

The wind deflection of transmission line means the wind deflection swing of insulator string and transmission conductor under the action of strong wind load. It may cause serious electric or mechanical trouble, so that it is harmful to the safe and stable operation of electric grid [1]. In general, only the design value or early-warning for wind deflection angle of insulator are analyzed by using the theoretical model or finite element program in the traditional studies [2-4], but paid less attention to the dynamic effect of wind deflection. In fact, owing to the fluctuating effect on wind field, there is certain difference between the static wind deflection calculated on the basis of average wind load and the actual maximum wind deflection of transmission line; in addition, the conductors in different phases may also incur non-synchronous swing in continuous strong wind, so that the inter-phase wind deflection flashover may be caused, and the success rate of post-tripping reclosing is relatively low. Therefore, in order to improve the design and early-warning accuracy for wind deflection of transmission line in strong wind area, it is necessary to calculate the dynamic wind deflection of transmission line in consideration of fluctuating wind effect.

In this paper, the generation method for fluctuating wind velocity in consideration of spatial correlation is discussed, then the wind load on every element node of conductor is determined on the basis of the calculation formula for wind load, and finally the dynamic wind deflection angle of insulator and the dynamic wind deflection displacement of conductor is calculated by using the nonlinear dynamic finite element method.



2. Generation methods for time-histories of random wind velocity

2.1. Average wind velocity

A lot of actually-measured data of wind field reveal that: The time-histories curve of wind includes long-period section and short-period section. Normally, the long period is more than 10min, far longer than natural vibration period of structures, and its effect on structures is equivalent to static effect; the short period is only several seconds or dozens of seconds, and its effect on structures is random dynamic excitation. On the basis of this principle, the wind field may be divided into average wind field and fluctuating wind field.

The average wind velocity can be obtained through altitude conversion on the basis of the basic wind velocity in the area where the transmission line is located. It is defined in the relevant code of China that: the basic wind velocity shall mean the 10min average maximum value of wind velocity occurred once in 50 years as measured at the position which is 10m above the ground in an open and flat area. The conversion of average wind velocity at the height of the conductor complies with the index ratio, and the specific calculation method is as indicated in the formula below:

$$\bar{v}(z) = \bar{v}_{10} \left(\frac{z}{10} \right)^{\alpha} \quad (1)$$

2.2. Fluctuating wind velocity

With respect to calculation for wind engineering, the generation of fluctuating wind is a very necessary work. At present, the generation methods for fluctuating wind can generally be divided into two categories: precursor simulation method and sequence synthesis method. The precursor simulation method means the method whereby a separate calculation domain is established for obtaining the fluctuating wind field before the main object of study is simulated. This method requires more time and storage space, so that the calculation cost is relatively high. The sequence synthesis method means the method whereby a group of time sequences of wind velocity which meet the designated conditions (power spectrum, turbulent intensity, integral scale, spatial correlation and etc.) are artificially synthesized, and mainly includes weighted amplitude wave superposition method and linear filtering method. In this paper, the linear filtering method is adopted to generate the fluctuating wind velocity.

Under this method, a series of random numbers of which the average value is zero and which have the white spectral properties are input into auto-regressive filter, so as to obtain the time-histories fluctuating wind velocity corresponding to the targeted wind velocity spectrum. The frequently used filter models include auto-regressive (AR) model, and auto-regressive moving average (ARMA) model.

The P-order AR filter model is as indicated in Formula (2):

$$v_0(t) = \sum_{k=1}^P \psi_k \cdot v_0(t-k\Delta t) + \sigma_N \cdot N(t) \quad (2)$$

Wherein: $v_0(t)$ is the simulated wind velocity; Δt is the time step; $N(t)$ is the normally-distributed random numbers of which the average is 0 and the variance is 1; P is the order of auto-regressive model; ψ_k is the auto-regressive parameter, which can be obtained on the basis of Formula (3):

$$R_v(j\Delta t) = \sum_{k=1}^P R_k \cdot [(j-k)\Delta t] \cdot \psi_k \quad j=1, 2, \dots, P \quad (3)$$

Wherein: $R_v(j\Delta t) = \int_0^{\infty} S_v(n) \cdot \cos(2\pi n \cdot j\Delta t) \cdot dn$; $S_v(n)$ is the designated fluctuating wind velocity spectrum (In this paper, the Kaimal spectrum is adopted for fitting).

In accordance with the *Load Code for the Design of Building Structures* [5], the wind velocity profile in height direction is as same as that in the formula (1), and the turbulent intensity profile meets Formula (4):

$$I(z) = 0.1 \times 35^{1.8(\alpha-0.16)} \left(\frac{10}{z} \right)^\alpha \quad (4)$$

Wherein: \bar{v}_{10} is the average wind velocity at standard height (10m); α is the surface roughness index ($\alpha=0.22$ under category-C landform is used).

2.3. Example for calculation of time-histories of random wind velocity

Assuming that the height of conductor is 40m and taking the average wind velocity for example, the time-histories of fluctuating wind velocity obtained through fitting is superimposed on the average wind velocity, so as to obtain the time-histories of random wind velocity at such height, as indicated in Figure 1.

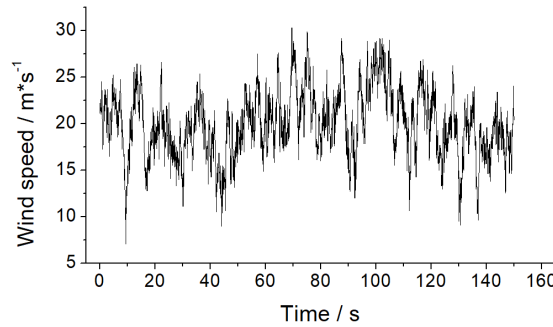


Fig. 1. Generated time-histories of random wind velocity

3. Calculation of dynamic wind deflection of transmission line

3.1. Determination of random wind load on transmission line

Giving the random excitation of node is the precondition for calculation of dynamic wind deflection of transmission lines. In accordance with the fitting method for time-histories of wind velocity as given in Section 2 and in consideration of spatial correlation, the time-histories of random wind velocity at the location of every node of conductor as indicated in Figure 2 can be obtained through fitting, and the coordinates of every node can be determined on the basis of catenary equation; and then the wind load on every node of conductor can be calculated by using Formula (5) (see Figure 3).

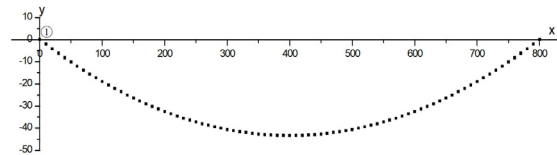


Fig. 2. Schematic diagram of nodes in span of conductor

The calculation formula for wind load per element length of conductor is:

$$W_x = 0.625 \alpha \mu_{sc} \beta_c (d + 2\delta) (K_h v)^2 \times \sin^2 \theta \times 10^{-3} = g_H \beta_c \sin^2 \theta \quad (5)$$

Wherein: α is the uneven wind pressure coefficient of conductor; μ_{sc} is the shape coefficient of conductor; β_c is the wind load adjustment coefficient for force applied by conductor on tower; v is the design wind velocity at the specified reference height h_s of transmission line; K_h is the height variation coefficient for wind velocity at average height of conductor; d represents the outside diameter of

conductor; δ is the icing thickness of conductor; θ represents the angle between wind direction and axial of conductor; g_H is the wind load per element length of conductor.

Assuming that the element length to which every node on conductor belongs is 1m, the time-histories of wind load of every node is as follows:

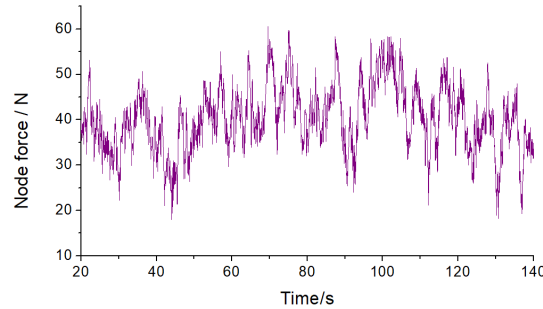


Fig. 3. Example of time-histories of random wind load of conductor

3.2. Nonlinear finite element dynamic analysis method

On the basis of the nonlinear finite element dynamic equation indicated in Formula (6), the horizontal displacement $d(t)$ of conductor in transmission line can be obtained, and then the dynamic wind deflection angle of insulator in transmission line can be obtained; wherein M , K and C are the mass, damping and stiffness matrix of conductor & insulator system respectively.

$$M\ddot{d}(t) + C\dot{d}(t) + Kd(t) = F(t) \quad (6)$$

The specific nonlinear solution process is as indicated in Figure (4).

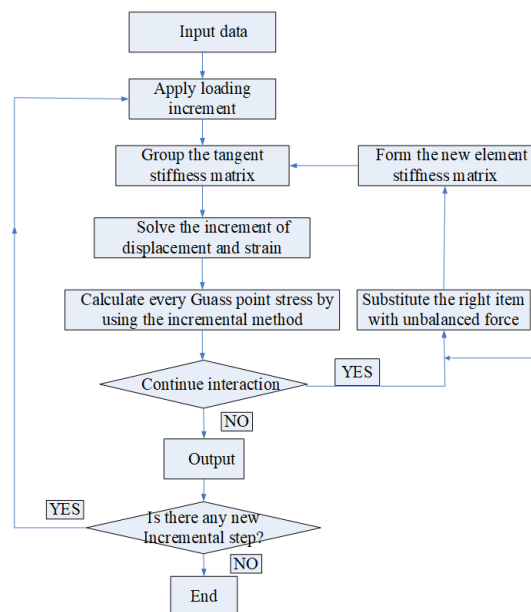


Fig. 4. Process of nonlinear finite element dynamic solution

3.3. Example for calculation of dynamic wind deflection

Taking a 220kV transmission line for example, where the span is 300m, the Type-I insulator strings are adopted, and the 2-split 400/35-steel-core aluminum strands are adopted as conductors. Assuming that the average wind velocity is 15m/s, the time-histories of wind load on nodes is re-generated on the basis of the method described in this paper; taking such time-histories as input conditions, the time-histories of displacement of conductor and time-histories of wind deflection angle of insulator are

obtained through nonlinear finite element dynamic analysis, as indicated in Figure and Figure 6 respectively.

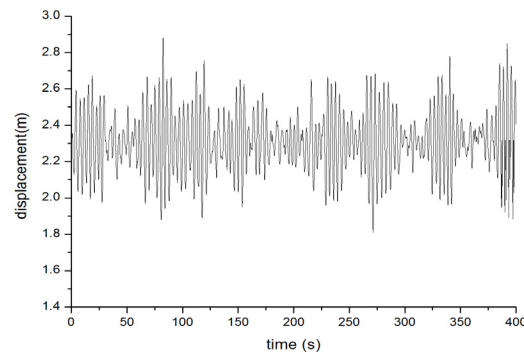


Fig. 5. Time-histories of horizontal angle of wind deflection of conductor

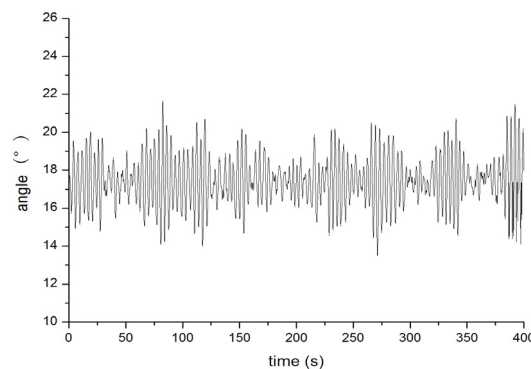


Fig. 6. Time-histories of horizontal angle of wind deflection of insulator

4. Summary

In this paper, in order to accurately simulate the wind deflection effect of transmission line in strong wind area, the generation methods for time-histories of random wind velocity and wind load of different nodes on conductor are brought forth in consideration of spatial correlation, and then the dynamic wind deflection of transmission line is calculated on the basis of the nonlinear finite element dynamic method, and the time-histories of wind deflection angle of insulator and the time-histories of displacement of conductor are obtained through solution of equation.

Acknowledgements

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