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Computational Analysis of 500kV Transmission Line Distortion Field near Trees

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Abstract

To study the influence of woods on electric field distribution of 500kV EHV Transmission lines, the Solidworks software was applied to create the simplified model of 500kV transmission lines, and the ANSYS software based on finite-element method was applied to calculate space electric field intensity of transmission lines. This paper chooses the electric field intensity of transmission lines and span central cross section as the research object. The calculation result shows that the maximum electric field intensity is about 1808v/m without woods and 1916v/m with 12m high woods and 2055v/m with 16m high woods in the middle of the span cross section 20 meters high above the ground. Woods around transmission lines can distort the space electric field of lines, and the higher of woods, the larger of the maximum of electric field over the woods. And using the method of unmanned aerial vehicle (uav) carrying measuring instruments to measure the cases with woods and without wood, respectively, and compare which with the calculation results to find that results of analysis are in agreement with the experimental datas basicly.This paper studies the space electric field intensity distribution of transmission lines under different height and location of woods, such can provide preference for reasonable erection of 500kV EHV transmission lines.

***Keywords**: EHV transmission lines, wood, finite elements analysis, ANSYS, electric field distribution*

1. Introduction

Now 500kV transmission line with widely coverage area, along the terrain, the case of transmission lines across the trees are more common. According to the "Forest Law" in China, trees of major project can not be cut down [1], so it is necessary to consider the distribution of trees. In addition to study the distribution of electric field around the transmission wire is important to High voltage transmission line construction, uav patrol and other engineering application.

In recent decades, domestic and foreign scholars have put forward different methods to measure the electric field distribution in the high voltage transmission lines. Markt-Mengele method is applicable for calculation of electric field intensity on the surface of four separate and below transmission wires [2]. Equivalent charge method is widely applied to calculate the space electric field intensity below transmission line [3], besides the Mirror image method step by step and finite element method can be used to calculate the space electric field intensity [4]. On the electromagnetic analysis research of transmission line, 2D electromagnetic calculation and analysis is used more than the research of 3D electromagnetic analysis, especially the electromagnetic effect caused by phase difference of three-phase transmission line, The finite element method is very much mature, which can effectively control error and improve the calculation accuracy in the treatment of the quasi static field and static field [5-7]. This article assumes that the

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insulator was on clean state, low humidity of the air , no corona being produced on line, and insulator string affected space electric field distribution around the conductor less, so the influence of the insulator string and the hardware is ignored. Therefore, first using the Solidworks software to set up the model of 500 kV ac transmission line, then which is imported into the ANSYS. The finite element method is used to simulate the model of quasi- static electricity field. At last, the final analysis calculated values were compared with the actual measurement values [8-10]. This paper adopted the way of unmanned aerial vehicle(uav) carrying measuring instruments to measure the electromagnetic field, to solve the problem of measuring electromagnetic field on the transmission line.

2. Fundamental Theory

2.1. Governing Equation

According to Maxwell's equations, the basic equations of electromagnetic field in the differential form.

$$\begin{cases} \nabla \times H = J + \partial D / \partial t \\ \nabla \times E = -\partial B / \partial t \\ \nabla \times B = 0 \\ \nabla \times D = \rho \end{cases} \tag{1}$$

If only consider the electric field, and power frequency voltage belongs low frequency AC signal, ignre $\partial B / \partial t$ of Equations (1) to simplify the calculation, quasi static electricity field control equation is obtained.

$$\begin{cases} \nabla \times E = 0 \\ \nabla \bullet D = \rho \end{cases} \tag{2}$$

Select potential φ as the solving object. According to Based on $E = -\nabla \varphi$ 、 $D = \varepsilon E$,it can be obtained that the equation.

$$\begin{cases} \nabla \times \nabla \phi = 0 \\ \nabla \left(\varepsilon \bullet \nabla \phi \right) = -\rho \end{cases} \tag{3}$$

For the three-dimensional rectangular coordinate system, the Formula (3) can be represented as:

$$\begin{cases} \frac{\partial}{\partial x}\left(\varepsilon \frac{\partial \varphi}{\partial x} \right) + \frac{\partial}{\partial y}\left(\varepsilon \frac{\partial \varphi}{\partial y} \right) + \frac{\partial}{\partial z}\left(\varepsilon \frac{\partial \varphi}{\partial z} \right) = 0 \\ \frac{\partial}{\partial x}\left(\varepsilon \frac{\partial \varphi}{\partial x} \right) + \frac{\partial}{\partial y}\left(\varepsilon \frac{\partial \varphi}{\partial y} \right) + \frac{\partial}{\partial z}\left(\varepsilon \frac{\partial \varphi}{\partial z} \right) = -\rho \end{cases} \tag{4}$$

Quasi-electrostatic field analysis must satisfy the above equation and the relevant boundary conditions. The finite element software has the advantages of strong commonality, easy operation, powerful calculation function and so on, the article uses the ANSYS finite element software to calculate the electromagnetic field.

2.2. Theory of the Finite Element Method

Finite element method is based on variational principle. First using the corresponding boundary conditions to transform differential equations into integral equations, then using subdivision interpolation technology of the discrete variational problem as ordinary multivariate function extremum problems to derive a set of linear algebraic equations. Solve the equations to obtain approximation solutions of boundary value problems [11].

By using the basic steps of finite element method:

1)To establish the integral equations. Actual problem areas, incentive and boundary conditions were determined， According to the variational principle to establish equivalent integral expressions of the boundary value problems of differential equations.

2)Subdivide computational domain. Cut it into a finite number, connected in a certain way and not overlapping units.

3)Choose the interpolation function. Select the appropriate interpolation function to solve the function of each unit with interpolation function approximation, a set of simultaneous algebraic equations were derived, known as the finite element equations.

4)Solve the finite element equations. Select the appropriate algebraic method to solve the finite element equations, and obtain the approximate solutions of of boundary value problems.

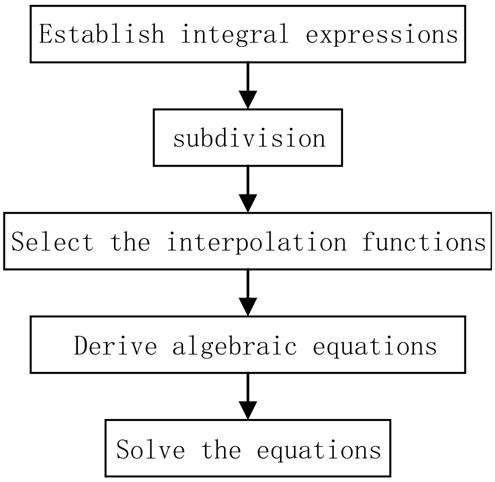


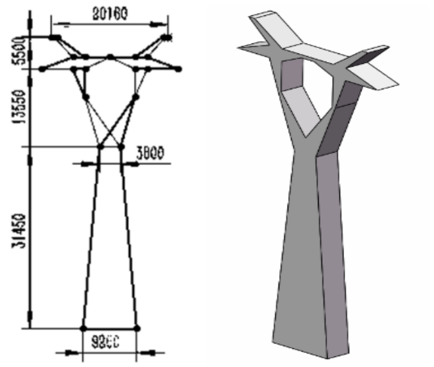
Figure 1. Basic Steps of Finite Element Method

2.3. Model

The tower adopts the type of ZBC3, and its size and model are shown in Figure 2. It can ignore the role of the insulator string because the insulator string distance from the measuring position is bigger, having less effect on the surrounding space electric field. Steel core aluminum stranded wire conductor is divided four LGJ - 400/35, divided spacing being 450 mm, the radius being 318 mm, span being 400 m, earth wire model being GJ70, height above the ground being 50.5 m, and earth wire being 20 m apart. Because the wire is fine, this paper uses the equivalent wire to replace (6), equivalent radius of the wire:

$$R_{eq} = R\left(\frac{\mathrm{mr}}{R}\right)^{\frac{1}{4}} = 318\times\left(\frac{4\times 13.41}{318}\right)^{\frac{1}{4}} mm \approx 204mm \qquad (5)$$

where R is divided radius, m is divided number, r is split sub-wire radius.



(a) size (b) 3D model

Figure 2. Size and Model of ZBC3 Tower

The species of trees studied in this paper were tree and fir because tree trunk is obvious much taller. When study the effect of trees on ehv transmission lines, calculation and analysis of the fir at the bottom of power transmission line were conducted. When fir wood moisture content is 12%, the relative dielectric constant is 2.67,cunninghamia lanceolata forest in the three dimensional model is shown in Figure 3.

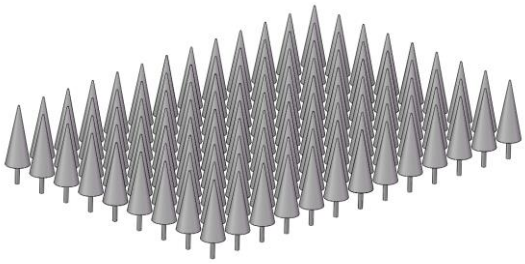


Figure 3. 3D Model of Cedars

3. Finite Element Analysis

3.1. Mesh

Woods ware growing near the 1/4 eiffel tower in the 500kV transmission line tower. Three-dimensional model thus was established along the X, Y axes of symmetry. This regional space of three-dimensional simulation model were including towers, wires, outsourcing and air. Outsourcing air of model is 1/4 cylinder ,radius is 20m, high is 70m. The outer radius was set 90m infinity-field region, as is shown in Figure 4.then the model was imported into ANSYS to conduct simulation. The 500kV transmission line model established in this paper is a more complex three-dimensional model of the structure. In the split aspects, it needs to choose the right way of splitting to ensure accuracy and increase computing speed [12-14]. part of Wire was using sweeping and meshing way; infinity-field region selection was choosing the hexahedral elements and using the mapping mode split. Specified area of wire was using the 0.5m of hexahedral element to obtain high precision calculations.

3.2. Constraints and Boundary Conditions

500kV AC transmission lines with voltage peak Um $\sqrt{2}\times 500/\sqrt{3}$, three-phase voltages are expressed as follows.

$$U_A = U_{\mathrm{m}} \sin(\omega \mathrm{t} + \varphi) \quad (6)$$

$$U_B = U_m \sin(\omega t + \varphi + \frac{2}{3}\pi) \tag{7}$$

$$U_C = U_m \sin(\omega t + \varphi + \frac{4}{3}\pi) \tag{8}$$

Considering the impact of transmission line phase, when voltage of phase conductors is Um, side phase conductor voltage values are -Um / 2.Press the boundary conditions on the ground, towers, lightning conductor and zero potential infinity is applied to calculate the electric field 500kV transmission line synthesis conditions.

4. The Calculation of Space Distortion Electric Field Around Transmission Lines

In order to study the influence of tree height on the space electric field distribution around transmission lines, the article respectively conducted electric field simulation of 12 m and 16 m high tree models which were compared to the calculation results without trees. The trees with the length and width are 60m and 40m respectively are just below the lines. The calculation model is shown in Figure 4. x represents the longitudinal, y direction transverse, z direction vertical direction

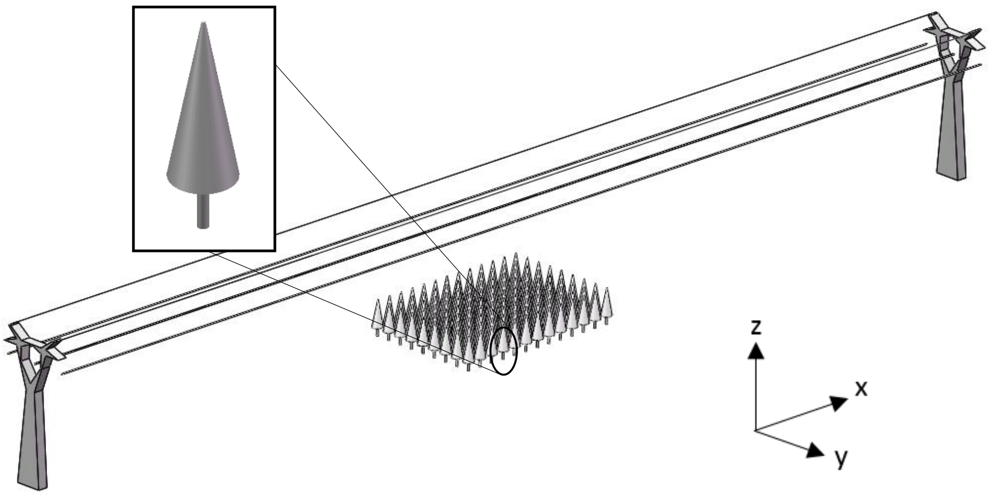


Figure 4. Calculation Model with Woods

In order to study the influence of trees on the distortion of space electric field distribution around transmission lines. 3D calculation model of lines with different heights of trees was set up, and the electric field distribution 20 meters high from the ground were calculated by ANSYS software. Then the space electric field distortion caused by tress was analyzed.

4.1. The Electric Field Distribution Around Transmission Lines without Tree

Figure 5, shows the electric field distribution curve in the middle cross section of span at the height of 20m from the ground without wood. Dc is the vertical distance from the center of line corridors and Esum is the synthesis value of electric field intensity.

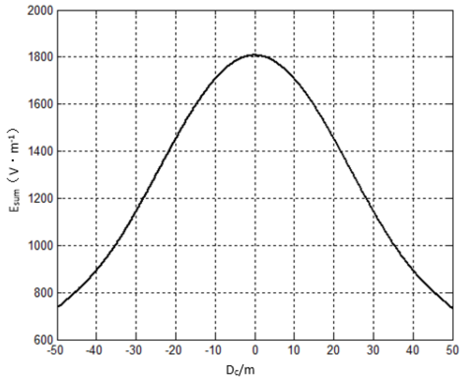


Figure 5. Electric Intensity Distrubution in the Middle Cross Section of Span without Woods (20 Meters above the Ground)

It is noticed that the maximum calculated electric filed intensity at 20 meters above the ground right appears below the center point of mid-phase conductor. The farther the lateral horizontal distance from the mid-phase line, the smaller the electric field intensity. Furthermore, Esum is inversely proportional to Dc approximately within the scope of 10~40m distance

Figure 6 shows the electric field intensity vertical distribution curve in a span without wood right below the mid-phase conductor at 20m above the ground. In the figure, Lb is the vertical distance from cross section in the center of span. It is noticed that the maximum calculated electric filed intensity, about 1808V/m, right appears in the center of the span. When near the Eiffel Tower, the longitudinal electric field intensity value decreased significantly, whose decline rate reaches $14.1V/m^{-2}$

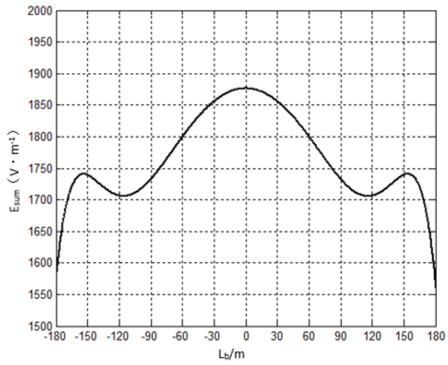


Figure 6. Electric Intensity Vertical Distrubution in a Span without Woods (20 Meters above the Ground)

4.2. The Effect of Trees on the Space Electric Field Around the Lines

This paper considers the effect of trees on the space electric field around the lines of different height. Figure 7, shows the calculated electric field intensity in the middle cross section of line span without wood and with the tree height of 12m and 16m. It is noticed that trees located at the center of span distort the space electric field distribution around the transmission lines. The maximum value and the distortion degree of electric field intensity increases with the increase of tree height from 12m to 16m. The maximum electric field is about 1916 V/m at the tree height of 12m and 2055v/m at 16m.

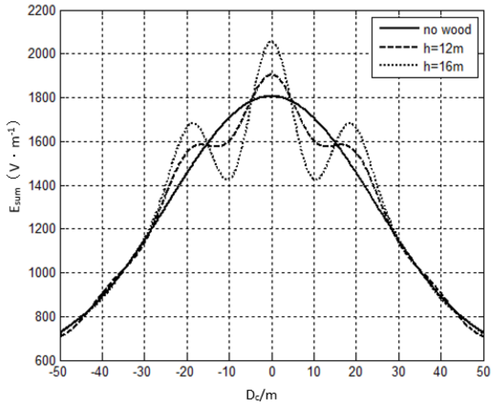
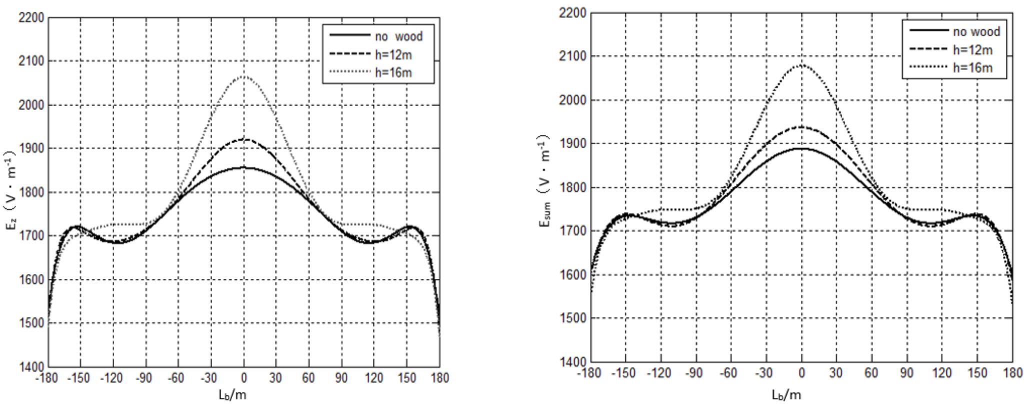


Figure 7. Electric Intensity Distrubution in the Middle Cross Section of Span under Different Height of Woods (20 Meters above the Ground)

At the height of 20m from the ground, the vertical component Ez and the synthetic value Esum of electric field intensity below the mid-phase conductor are shown in figure 8 where Ld is the vertical distance from the middle cross section of line span. It is noticed that the maximun electric field intensity increases with the increase of tree height and the vertical component is the main part of the electric field intensity vector.



(a) E_z (b) E_{sum}

Figure 8. Ertical Distrubution of Electric Intensity in a Span under Different Height of Woods (20 Meters above the Ground)

4.3. The Measurement of Electric Field Intensity Using Unmanned Aerial Vehicle with Electromagnetic Measurenment Instrument

Figure 9, and Figure 10, show the test process in which the electromagnetic tester (HI3604) carried by a rotor unmanned aerial vehicle (UAV) measured the space electric field intensity around the transmission lines. The rotating blades of the UAV is made of non-metallic materials and the tester keeps outside the vehicle body via a fixed rods to avoid the influence of the vehicle on the measured value. A GPS which can record the location including height and the horizontal distance from the lines and then transmit the data to the ground station is placed on the vehicle. Maybe the measured values have a certain deviation with the calculated values. But the deviation, lower than 10%, is still acceptable which verifies the reasonability of the measuring method in a way.

Figure 9. GPS Interface in the Air Test

Figure 10. Data of Test Instrument

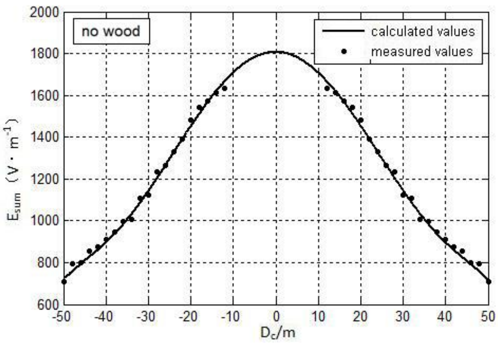


Figure 11. Measured Values of Electric Intensity Distrubution in the Middle Cross Section of Span without Woods under Lines (20 Meters above the Ground)

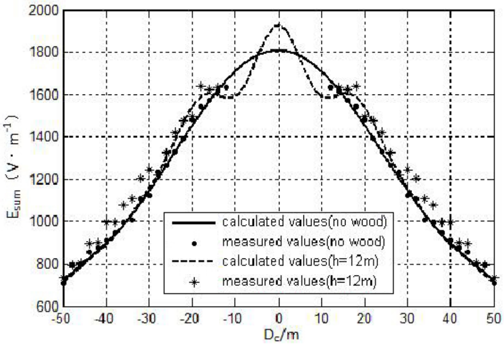


Figure 12. Measured Values of Electric Intensity Distribution in the Middle Cross Section of Span with the Calculated Area of Transmission Lines (20 Meters above the Ground)

4.4. The Safe Distance between Trees and Lines

4.4.1. Minimum Distance between Lines and the Ground: According to the frequency electric field intensity threshold at 1.5m above the ground which is 4kV/m, the minimum height of lines from the ground is 18m under ideal condition.

4.4.2. The Analysis of the Minimum Vertical Distance between the Top of the Trees and Lines: Generally, there must be enough distance between trees and lines. Leaves at the end of branches shows the signs of burn under high electric field intensity when the distance is not long enough [7]. while the height of lines is designed to 28m, the maximum electric field intensities at the top of trees with different height of trees ignoring the effect of weather and environment are shown in Table 1, where h is the height of trees.

Table 1. Cases of the Electric Field Intensity for the Synthesis of the Tops of Woods

h(m)	Electric field intensity (kV/m)
21	52
23	83
25	152
26	231
27	812
27.5	1020

It is noticed that the electric field intensity reach 52kV/m with the tree height of 21m. As the height of trees increases, the value and distortion degree of the electric field intensity increases gradually. Once the distance between trees and lines is shorter than the safe threshold, corona discharge phenomenon will appear at the top of tree under severe condition such as rain or dust, and even more serious than that there is the risk of electric shock.

5. Conclusions

1) When there is no wood, the space electric field intensity around the transmission lines has approximately inversely proportional relationship with the horizontal distance from the center of line corridor in the range from 10~40m.
2) The maximum longitudinal electric filed intensity calculated right appears in the center of the span. The space electric field intensity decreases obviously near the tower.
3) When there are trees located at the center of span, the space electric field distribution around the transmission lines distorts. The maximum value and the distortion degree of electric field intensity increases with the increase of tree height and the vertical component is the main part of the electric field intensity vector.
4) In this paper, the measured and calculated values of electric field intensity around the transmission lines are consistent generally which verifies the measuring method is reasonable.

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