Tree Barrier Prediction of Power lines based on Tree Height Growth Model

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Abstract. Aiming at the problem that the hidden trouble of tree barrier seriously threatens the safe operation of power lines, the typical tree species in the corridor of power lines in Guangdong area are investigated and studied. Firstly, a tree height growth prediction model based on Richard’s equation is established. The correlation deviation test results show that the model can accurately predict the tree height. The hidden trouble of tree barrier under line and the hidden trouble caused by wind deviation of wire are analyzed. Finally, the model for predicting the clearance distance from tree to power lines is established. By predicting the clearance distance between wire and tree, the functions of real-time detection of hidden trouble of tree barrier and risk assessment and prediction of tree barrier are realized. It avoids the flashover fault caused by the excessive growth of trees, and ensures the safe and stable operation of power lines.

1. Introduction
Thanks to rapid development of China’s forestry industry, the national program of “returning farmland to forestry” and stringent requirements for sustainability, forest households have planted a large number of fast-growing economic trees in the mountain areas. Some of the trees may have a maximum annual growth rate of more than 6 meters, with a total height of 25 meters. Both existing power lines or newly built lines cannot meet the requirement of safe operation. The expansion of power network gives rise to constant addition of power lines. Some of the lines have to go through economic forest zones or forest areas with dense trees. As a result, the conflict between power lines and plants such as trees and bamboos and the safety of overhead power lines have become more and more prominent. According to statistics, power suspension caused by tree barrier keep happening around the globe. Hidden trouble of tree barrier has seriously threatened the safety of power lines [1-4].

Generally speaking, three types of conventional methods exist for predicting hidden troubles of tree barriers. The first method is to mount camera devices on each tower of the transmission line to judge if there is any hidden danger by taking photos. The second method is featured by the use of the airborne lidar technology to collect radar point cloud data of power line corridors to analyze if there exists hidden danger of tree barriers. The third method is that a line inspector carries a laser range finder to regularly measure the distance between the wire and the tree height in the line corridor to judge if there is any hidden danger. However, problems due to tree barriers of extra height still occur from time to time, as the tree height acquired through conventional methods are static results at a certain moment. Line inspectors can hardly measure the exact height of a tree purely with their eyes based on experience, as trees keep growing year on year along the two sides of the line corridor or under the power lines. Therefore, there may be huge discrepancy between the actual situation and measured data, resulting in low detection accuracy of hidden trouble prediction. When the wire sag increases or the wind deflects...
with the strong wind, clearance distance between trees and power lines is less than the air critical breakdown distance, the tree flash failure will occur. So, conventional methods are unable to catch up with rapid development of power lines [5-6]. Based on the study of typical types of trees along the power lines corridor in Guangdong province, this paper proposes a model for predicting the clearance distance from tree to power lines based on height growth prediction model of Richard's equation with an aim to provide early warning against the hidden trouble of tree barrier, avoid the tree flash failure and ensure safe operation of transmission lines.

2. Tree height growth prediction model

2.1. Richard's Equation

Tree height growth prediction model is to reflect the change of tree height with tree age under the influence of various factors that may affect the growth of the tree such as temperature, moisture and soil. An S-shaped curve equation is used to reflect the growth cycle of trees, as the growth rate of trees is featured by four stages, slow growth, vigorous growth, slow growth, and stop growing with time. Richard's equation is a typical nonlinear regression model. It is based on different factors of tree species, describing the change of tree height growth over time. The parameters of this equation have obvious biological significance. With different values of the parameters in the equation, they can form the growth equations of different organisms, for a wide range of adaptability, reasonable analysis and good predictability [7-11]. Therefore, Richard's equation is adopted to predict the growth height of trees in the power line corridors. Richard's equation is shown as below,

\[
h = a \left( 1 - e^{-kt} \right)^c \]

Where \( h \) is the height of the tree, \( t \) is the age of the tree. The parameters \( a \), \( k \), and \( c \) are the growth factors. \( a \) is related to the height of the tree, representing the maximum height of the tree. \( k \) is related to the growth rate of the tree, standing for the growth rate of the tree. \( c \) is related to the curve shape of the equation, determining the position of the inflection point. The higher the accuracy of the inflection point, the higher the accuracy of the equation simulation [12].

2.2. Solving the parameters of tree height growth model in Guangdong area

Guangdong Province has a flat terrain with rich light, heat and water resources. It is classified as the subtropical monsoon climate. Typical tree species along the power line corridors in the province are eucalyptus, camphor, and Guangdong pine. Due to the different growth speeds and growth cycles of different tree species, models for predicting the tree height growth also vary. Parameter solving process is analyzed by taking eucalyptus as an example. Eucalyptus with different height under different conditions are selected, as shown in Table 1.

| Tree age /t | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|------------|----|----|----|----|----|----|----|----|----|----|----|
| Tree height /m | 7.3 | 9.8 | 12.4 | 13.38 | 14.87 | 17.01 | 17.5 | 18.07 | 18.54 | 19.01 | 19.23 |
| Tree age /t | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Tree height /m | 7.0 | 9.3 | 11.8 | 12.76 | 14.23 | 16.41 | 17.02 | 17.59 | 18.11 | 18.43 | 18.56 |
| Tree age /t | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Tree height /m | 7.5 | 10.1 | 12.39 | 13.58 | 15.05 | 17.34 | 17.66 | 18.36 | 18.82 | 19.43 | 19.76 |

Use Matlab to draw a scatter plot of eucalyptus tree age-tree height observations and add a trend line, and fit it to get the regression equation,

\[
h = -0.101t^2 + 4.106t - 23.327 \]

Insert tree ages of 10 years, 15 years, and 1920s into the regression equation, the corresponding theoretical tree height values are \( h_1=7.633 \), \( h_2=15.538 \), and \( h_3=18.393 \). Substitute \( h_1 \), \( h_2 \), \( h_3 \) into the Observation Ratio Formula,
The observation ratio \( \lambda = 0.764 \). Then substituting \( h_1, h_2, h_3 \) into Richard's Equation (1) and Observation Ratio Formula (3) respectively, and we can get,

\[
\lambda = \frac{\log(h_2 - h_1)}{\log(h_2) - \log(h_1)}
\]

Let \( e^{-10k} = x \), we can get,

\[
(1 + x)^{0.744} (1 - x) + x^{1.1} = 1
\]

Then use Matlab to solve the Equation (5), so as to solve the parameter values of Richard's equation, and finally get,

\[
y = 20.7421 (1 - e^{-0.241})^{1.314}
\]

Follow the same steps, insert the observation data of camphor, and Guangdong pine, the tree height prediction model of such trees can be obtained in the same way,

\[
y = 13.52 (1 - e^{-0.112})^{1.28}
\]

\[
y = 24.163 (1 - e^{-0.157})^{1.449}
\]

3. Tree barrier warning model

3.1. Tree barrier warning model for trees under power lines

A. Wire sag model

Under normal circumstances if the tree height can meet safety requirement of power lines in terms of clearance distance, failure of flash tree will not occur. However, if the wire sag increases, even if the trees no longer grow taller, a tree flash failure may occur. Especially in the summer when the weather is hot, the electricity load reaches its peak, further aggravating the temperature rise of the wire. At this time, the wire sag is greatly increased than normal. When the clearance distance between the tree and power line is less than the air critical breakdown distance, the tree flash failure will occur. The size of the wire sag is relevant with the operating current, ambient temperature, light, wind speed and other factors of the wire. When these factors are constant, the calculation formula of the wire sag is,

\[
f = \frac{ws^2}{8g}
\]

Wherein \( f \) is the sag of the conductor, \( g \) is the horizontal stress of the conductor; \( w \) is the load per unit length of the conductor; \( s \) is the pole tower span [13].

B. Clearance distance model from trees to power lines

The trees on both sides of and directly below the transmission line corridor grow taller with tree age, while the sag of the wire will also increase under certain circumstances. When the clearance distance between the tree and line is less than a critical air breakdown distance, a tree flash failure will occur. According to the mechanism of the tree barrier, the Richard tree height growth prediction model and the wire sag model are used to construct the clearance distance model between the tree and the wire,

\[
H = y - f - h
\]

Wherein \( H \) is the minimum clearance distance between the tree and the wire; \( y \) is the height of the tower; \( f \) is the sag of the wire at any point; \( h \) is the height of the tree.

3.2. Models of the hidden trouble of tree barrier under line and the hidden trouble caused by wind deflection of wire

A. Mechanism for tree barriers and power lines wind deflection

In the construction phase of power lines, the designer has considered the meteorological conditions and adopted measures such as installing anti-vibration hammers and V-shaped insulating strings to
prevent the line from swinging or twisting due to strong winds in operation. At the operation phase, trees under power line keep growing over time. Wires also deflects under wind load. Thus, the clearance distance between power lines and the adjacent trees are reduced. When such distance is less than the critical air breakdown distance, tree flash failure will happen.

B. Clearance distance model for power lines with wind deflection and tree barrier

As shown in Figure 1, AB is the trajectory of the wind deflection of the wire. According to the tree flash failure caused by the wind deflection of the wire, it can be obtained from Figure 1,

$$\cos \theta = \frac{y-f-h}{H}$$  \hspace{1cm} (11)

Wherein $H$ is the minimum clearance distance between the tree and the wire, $y$ is the height of the tower; $f$ is the sag of the wire at any point, $h$ is the height of the tree. From the moment of balance equation, the wind deflection angle $\theta$ of the wire is,

$$\theta = \tan^{-1} \left( \frac{g_1}{g_2} \right)$$  \hspace{1cm} (12)

Where $g_1$ is the weight of the conductor, $g_2$ is the wind load. Combining Equation (11) and (12), the model for predicting the minimum clearance distance between the tree and line subject to wind deflection is constructed,

$$H = \frac{y-f-h}{\cos(\tan^{-1} \left( \frac{g_1}{g_2} \right))}$$  \hspace{1cm} (13)

In combination with Richard Equation for tree height growth model, tree flash failure can be predicted for a certain period of time under certain climatic conditions.

### Figure 1

![Schematic diagram of a power line under wind deflection](image)

4. Verification of the results

4.1. Accuracy test of tree height growth prediction model

Tree height growth model needs to be verified to ensure the accuracy of tree barrier warning. Use Matlab to linearly fit the predicted and observed values of tree heights, and then use R-squared ($R^2$), mean deviation (MD), and mean absolute deviation (MAD) and root mean squared error (RMSE) to test the prediction accuracy of the model [14-15], the test formula is as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \hat{y})^2}$$  \hspace{1cm} (14)
\[ MD = \frac{1}{n} \sum_{i=1}^{n} (y_i - y'_i) \]  
\[ MAD = \frac{1}{n} \sum_{i=1}^{n} |y_i - y'_i| \]  
\[ RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - y'_i)^2} \]

In Equation (14) to (17), \( y_i \) is observation value of the tree height, \( y'_i \) is prediction value of the tree height, \( \bar{y} \) is mean observation value of the tree height, \( n \) is the number of samples, while \( p \) is the number of model parameters. Accuracy test result of tree height growth prediction model is shown in Table 2.

| Species types   | \( R^2 \) | MD     | MAD    | RMSE    |
|-----------------|---------|--------|--------|---------|
| Eucalyptus      | 0.9103  | -0.0136| 1.1052 | 1.4125  |
| Camphor         | 0.8846  | 0.00935| 1.0275 | 1.2026  |
| Guangdong pine  | 0.8926  | -0.0212| 1.0344 | 1.6123  |

As shown in Table 2, the \( R^2 \) of the tree height growth prediction model of the selected tree species all close to 1, demonstrating a high goodness of fit, MD, MAD and RMSE are all small and close to 0. From the results, we can judge that tree height growth model parameters of the selected tree species are solved reasonably and the tree height growth prediction model has high accuracy, which is suitable for early warning of the hidden trouble of tree barriers.

4.2. Accuracy test of tree barrier warning model

With the area along the 10kV Xinjia Line and the 10kV Jichang Line as the research objects, we carried out two-year prediction for the clearance distance from the power line to a specimen of trees on both sides of the line corridor and under the line, and observed the actual clearance distance every year. Clearance distance model from trees to power lines for tree barriers is predicted according to the maximum sag, and the wind deflection tree barrier model is predicted based on the maximum wind deviation distance. The recorded data is shown in Table 3.

| Line name | Species types | year \( t \) | Tree barrier model under line | Wind deflection tree barrier model |
|-----------|---------------|-------------|-------------------------------|----------------------------------|
|           |               |             | forecast H/m | Measurement H/m | deviation \%/ | forecast H/m | Measurement H/m | deviation \% |
| Xinjia Line | Eucalyptus    | 1           | 2.38           | 2.53               | -5.93          | 3.12          | 3.36               | -7.14            |
|           |               | 2           | 1.91           | 2.05               | -6.83          | 2.92          | 3.15               | -7.30            |
| Jichang Line | Camphor      | 1           | 3.07           | 2.94               | 4.42           | 2.63          | 2.52               | 4.37              |
|           |               | 2           | 2.44           | 2.34               | 4.27           | 2.20          | 2.10               | 4.76              |

As shown in Table 3, both the deviation between clearance distance from trees to power lines predicted by the two models and the actual measured value is less than 10%, of which the positive deviation is less than 5%. It proves that the model has high accuracy and can realize the early warning of tree barrier hidden dangers.

5. Conclusion

In this paper, we have developed tree height growth model based on Richard's Equation for typical trees growing under the power lines corridor in Guangdong Province with high prediction accuracy, which can also be applied to predict the growth height of other tree species. Combining the wire sag model and the wind deviation mechanism of the wire, we have developed a model for clearance distance from tree to power lines separately to fulfill the following two functions.

1. Real-time detection of hidden trouble of tree barrier
The tree height growth prediction model is used to predict the current tree height. At the same time, the real-time sag and wind deflection of the wire are calculated according to the current ambient temperature, light, wind speed and wire load current. The clearance distance model between power lines and trees is used for real-time detection of the hidden trouble of tree barriers below and on both sides of the power lines. When $H$ is greater than or equal to the safe distance of wire travel, tree flash failure will not occur on power lines. When $H$ is smaller than the safe distance of wire operation, tree flash failure is quite likely to occur under current load. Maintenance staff should promptly reduce the power load or trim tree toppings to avoid such danger and ensure safety of the power lines.

(2) Risk assessment and early warning of hidden trouble

Tree height and the time of tree flashover failure in the next few years can be predicted with the help of the tree height growth prediction model. In line with the regulations on the safety distance of different voltage levels, engineers can assess the risk level of tree barriers according to the clearance distance between trees and power lines to issue an early warning of tree barrier risks. In this way, engineers will be kept abreast of the hidden trouble of tree barriers in challenging areas to patrol and inspect power lines. It can also prevent fire disasters and personal accidents in the forests if the conflicts between trees and power lines can be promptly resolved and tree flash failure can be avoided.

Clearance distance model from trees to power lines can provide scientific basis for power line maintenance engineers to work out plans to address the hidden trouble of tree barrier. It has transformed static management of tree barrier based on experience to dynamic prediction of tree height. So, it helps to build a reliable power transmission network by greatly reducing prediction errors and preventing tree flash failure due to tree height growth.

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References

[1] Fan C. Data analysis, Proposals for Management and Control of Hidden Dangers of Tree Barrier in overhead Power Lines [J]. Guangxi Electric Power, 2017, 40(001):46-48.
[2] Liu H, et al. Analysis of Tree Flash Fault in Power Lines from the Viewpoint of Power Blackout [J]. Power System Technology, 2007(S1):67-69.
[3] Liu H, et al. Analysis of Tree Hazards in Power Transmission Corridors and Research on Vegetation Management Strategies [J]. Heilongjiang Electric Power, 2019, 041(001):64-67.
[4] Zhou Y, et al. Study on the Growth Law of Trees with Extra Height under overhead Power lines[J]. Journal of Central South University of Forestry and Technology, 2016, 36(02):75-78.
[5] Lu H. Research on the Treatment Methods of Regenerated Tree Species along Power Line Channels [J]. Low Carbon World, 2017, (033): 68-69.
[6] Zheng Y. Research on Key Technologies for Online Monitoring of Tree Barriers in Overhead Power Line Corridors [J]. Mechanical and Electrical Information, 2014, 14(2): 150-151.
[7] Miehle P, et al. A comparison of four process-based models and a statistical regression model to predict growth of Eucalyptus globulus plantations [J]. Ecological Modelling, 2009, 220(5):734-746.
[8] Wei X, Sun Y, Ma W. Fir Trees Height Growth model based on Richards Equation [J]. Journal of Zhejiang A&F University, 2012, 29(005):661-666.
[9] Xiang N. Analysis of Tree Height Growth Model based on Richards Equation and Determination of Parameters[J]. Anhui Forestry Science and Technology, 2015(03):71-74.
[10] Li F, Wu J, Lu S. Comparison between Richards Function and Schnute Growth Model [J]. Journal of Northeast Forestry University, 1993, 21(4): 15-24.
[11] RICKER W E. 11 Growth rates and models [J. Fish Physiol, 1979, 8.677 — 743.
[12] Zhu H, Yu Z, Yan J. Prediction and Simulation Analysis of Hidden Dangers from Tree Barrier in UHV Transmission Lines [J]. Journal of Northeast Electric Power University, 2018, 38(2):21-
27.

[13] Li G, Yin P. Analysis and Research on Tree Faults in Transmission Lines[J]. Modern Industrial Economics and Informatization, 2018,008(017):103-105.

[14] Lin L, et al. Research on the Growth Law and Growth model of Cinnamomum Camphora Trees in Guangdong Province[J]. Journal of Central South University of Forestry and Technology, 2018, 038(006):23-29.

[15] Zhang X, et al. Tree Height Growth Model of Chinese Fir Plantation based on Bayesian Method [J]. Forestry Science, 2014, 50(003):69-75.