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To cite this article: Jian Liang et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 234 012067

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IOP Conf. Series: Earth and Environmental Science 234 (2019) 012067

Wind Turbine Simulation Based on CFD Optimization Algorithm

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Abstract. Blade profile changes lift and drag on the surface. So it is necessary to measure the power change of the wind turbine in the cold area by simulating the icing process. Computational fluid dynamics is considered as an effective method to predict ice accumulation. In this paper, the formation process of glaze ice was simulated by heat and mass transfer balance. The numerical calculation of 3-d blades was optimized by node interpolation and time step. Results show that the collision coefficient and ice shape would be changed by increasing the number of grid nodes. Through multi-step time iteration, it is easier to get the biangular ice in line with the actual situation.

1. Introduction

As the most economically competitive new energy source, wind power plays an important role in the diversification of energy security, energy supply, economic growth and greenhouse gas emission reduction. The icing environment changes the geometric shape and surface roughness of the blade, leading to serious power loss of the wind turbine.

Some studies on the wind turbine icing simulation have been proposed such as Lewice ^[1], FENSAP-ICE^[2], Turbice^[3]. These were based on the computational fluid dynamics (CFD), and used to predict the ice shape. It has been proved that the rime ice accretion can be predicted accurately, but the glaze ice still needs improved ^[2].

In the numerical calculation of wind turbine icing, reports on the detailed calculation of grid and the iterative process of ice shape are rarely mentioned. In this paper, the blade icing calculation was optimized by linear interpolation and mesh reconstruction, and the dynamic change process of blade icing was obtained. The parameters such as collision coefficient and ice shape before interpolation were compared. The results of this paper have a general reference for numerical simulation of the icing process.

2. Numerical Calculation of Ice Growth

2.1. Mathematical Model of Ice Growth

In the numerical calculation of wind turbine icing growth, the collision of water droplets and the freezing process on blade surface are usually considered. According to the numerical model of iced blade ^[4], the two processes of mass and heat balance are respectively expressed as:

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$$\begin{cases} m_{im} + m_{in} = m_{out} + m_{eva} + m_{ice} \\ Q_{im} + Q_{in} = Q_{eva} + Q_{ice} + Q_{out} + Q_f + Q_c \end{cases}$$
(1)

Where, m_{im} and Q_{im} are the mass and energy of the supercooled droplets impinging onto the blade profile. m_{in} and Q_{in} denote the mass and energy of previous water coming into the cell. m_{out} and Q_{out} denote the mass and energy of water flowing out to the next cell. m_{eva} and Q_{eva} are the mass and energy of evaporating water. Q_f is the friction heat, Q_c is the convective heat ^[4].

In GAMBIT, the non-structural grid is adopted to complete the geometric modeling. The horizontal position of the blade is 5 R from the velocity inlet and pressure outlet. The external flow field is divided into static flow field and rotating flow field. The rotating flow field adopts MRF model^[5] to simulate rotation.

The collision process of water droplet is simulated by Euler two-phase flow. The water droplet is regarded as continuous term, and the distribution of water droplet in solution domain is reflected by the droplet volume fraction α . SIMPLE algorithm is used to solve the Navier-Stokes equation for steady viscous flow. Convergence criterion is considered in k- ϵ turbulence equation. The governing equation of water droplet motion is expressed as:

$$\begin{cases} \frac{\partial(\rho_w \alpha)}{\partial t} + \nabla \cdot (\rho_w \alpha \overline{V_w}) = 0\\ \frac{\partial(\rho_w \alpha \overline{V_w})}{\partial t} + \nabla \cdot (\rho_w \alpha \overline{V_w} \overline{V_w}) = \rho_w \alpha K(\overline{V_a} - \overline{V_w}) \end{cases}$$
(2)

Where, *a* and *w* are air terms and water drop terms respectively. The simulation of air flow field and water drop collision of wind turbine is shown in Fig 1. The height of the first layer grid is between 30 and 50, so that it meets k- ϵ turbulence equation.



Figure 1. Eulerian two-phase flow simulation

2.2. Ice Growth and Grid Changes

In 2.1, the ice thickness under the time step of each grid is obtained, and the new ice shape needs to be solved. The ice layer grows along the normal direction of grid. The ice layer advance was carried out in the x-y coordinate system. The ice shape along each segment of the blade was respectively calculated and plotted, and finally the sections were connected together to obtain three-dimensional imaging. As shown in Fig 2, node 3 is the initial grid at a certain time. After a time step, the adjacent grid ice thickness is h_{23} and h_{34} . Then, node 3 moves along the outer normal direction of dotted line l_{24} , $d_3 = 0.5$ ($h_{23} + h_{34}$). Node 3' is the new position after a time step.



Figure 2. Ice growth mode

2.3. Mesh Reconstruction

The moving mesh method can shrink or stretch the grid, so as to simulate blade profile changes due to icing. It is effective to deal with small deformation of motion boundary. The spring force on any node i at the boundary of blade wall is expressed as:

$$\overline{F}_{i} = \sum_{j}^{n_{i}} k_{ij} (\Delta \overline{x}_{j} - \Delta \overline{x}_{i})$$
(3)

Where, n_i is the number of all nodes adjacent to node *i*, and Δx_i is the position vector of node. k_{ij} is the spring stiffness coefficient, which is expressed as:

$$k_{ij} = \frac{1}{\sqrt{\left|\vec{x_j} - \vec{x_i}\right|}} \tag{4}$$

When the force is balanced, the net force of the spring at the node is 0, so the iterative equation obtained is as follows:

$$\Delta \vec{x}_{i}^{m+1} = \frac{\sum_{j}^{n_{i}} k_{ij} \cdot \Delta \vec{x}_{j}^{m}}{\sum_{j}^{n_{i}} k_{ij}}$$
(5)

Equation (5) adopts Jacobin Matrix to scan all internal nodes, setting the number of iterative steps to 10 times. Generally, it can achieve stable convergence after 5~6 iterations, as shown in Fig 3.



Figure 3. Grid remesh after icing

3. Results and Analysis of Ice Growth

3.1. The Effect of Linear Interpolation of Grid Nodes

Due to the limited calculation amount, the segmentation of local blade grid is not as accurate as that in 2d. In this paper, the number of blade surface grids is around 70,000. Taking the blade tip section as an example, the number of nodes forming the airfoil is about 60, but the actual grid on icing condition is less. So it is difficult to capture the more accurate ice shape. By the central difference method, linear interpolation was carried out for the number of all local grid nodes on the blade wall surface, and the number of nodes in the section was expanded to 90 and 180, respectively, as shown in Fig 4.



Figure 4. Node changes after interpolation

The ice growth with different nodal Numbers was simulated. The ice shape and local collision coefficient β contrast at the blade tip is shown in Fig 5. By comparing the ice shape with different grid nodes, it can be seen that the ice shape is more smooth with the more grid nodes. Especially at the leading edge of the blade, the over-sparse grid will lead to ice shape distortion, and the ice thickness difference between the grids is obvious. It can be seen that the increase of the number of grid nodes makes the ice thickness of each grid better continuity. This is more in line with the actual ice situation.

Besides, in the limit position of ice cover, the sparse grid will lead to larger ice cover area. This is mainly for the reason of low calculation accuracy of local collision coefficient. As shown in Fig 5 (b), the maximum value of local collision coefficient at 60 nodes is relatively low, where droplet actually does not reach. As a result, ice shape calculation of 60 nodes tend to predict more ice on suction surface.



(a) Ice shape at tip

(b) Local collision coefficient

Figure 5. Grid and node effects on numerical calculation

3.2. The Dynamic Process of Ice Advance

By using time multistep method to simulation the ice growth, the blade profile can be constantly updated, so that local collision coefficient changes correspondingly with time. Ice growth with time is simulated, on the condition that: wind velocity 7 m/s, liquid water content 0.5 g/m³, droplet diameter 20 μ m, temperature -8.0°C, icing time 80 min and the time step 10 min.

With multiple iterations of the ice layer, the edge angles of the ice layer on the pressure surface and

suction surface at both ends of the stagnation point became more and more obvious, as shown in Fig 6. This is for the reason that the configuration of biangular ice results in significant changes in the distribution of local collision coefficients. Local collision coefficient usually shows maximum value at ice angular, and its distribution no longer keeps regularly as in Fig 5. As a result, local ice thickness presents a more obvious maximum value at both sides of the stagnation point, and the variation of biangular ice becomes more and more obvious.



Figure 6. Ice layer changes with iterations

4. Conclusion

In this paper, interpolation function is introduced by using central difference method of boundary. Boundary reconstruction by moving mesh and ice advancing by time multistep method are also used to optimize ice construction. So the dynamic change of ice during blade icing process is obtained. Results show that the larger number of nodes in the blade grid obtained by linear interpolation, the smoother ice shape is, and the more accurate the calculation result of local collision coefficient is. In the process of icing, the leading edge of the blade gradually formed biangular ice.

5. Acknowledgment

This work was supported by National Natural Science Foundation of China (61503216) and Science & Technology projects of State Grid Shandong Electric Power Company (5206021700TW, 2018A-037).

6. References

- [1] Ruff, G.A. and B.M. Berkowitz, Users manual for the NASA Lewis ice accretion prediction code (LEWICE) (1990)
- [2] T. Reid, G. Baruzzi, I. Ozcer, et al. FENSAP-ICE simulation of icing on wind turbine blades, part 1: performance degradation. 51st AIAA aerospace sciences meeting including the new horizons forum and aerospace exposition, Grapevine, Texas (2013)
- [3] Marjaniemi, M., L. Makkonen and T. Laakso. Turbice-the wind turbine blade icing model. in Proceedings of the BOREAS V conference, Finnish Meteorological Institute (2000)
- [4] Lichun S, Jian L, Qin H, et al. Study on Small Wind Turbine Icing and Its Performance. Cold Regions Science and Technology, 134: 11-19 (2017)
- [5] P Fu, M Farzaneh. A CFD approach for modeling the rime-ice accretion process on a horizontalaxis wind turbine. Journal of Wind Engineering and Industrial Aerodynamics, 98(4-5): 181-188 (2010)