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Transient flow analysis for horizontal axial upper-wind turbine

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Abstract : *This study is to carry out a transient flow field analysis on the condition that the wind turbine is working to generate turbine, the wind turbine operating conditions change over time, Purpose of this study is try to find out the rule from the wind turbine changing over time . In transient analysis, the wind velocity on inlet boundary and rotation speed in the rotor field will change over time, and an analytical process is provided that can be used for future reference. At present, the wind turbine model is designed on the concept of upwind horizontal axis type. The computer engineering software GH Bladed is used to obtain the relationship between the rotor velocity and the wind turbine. Then the ANSYS engineering software is used to calculate the stress and strain distribution in the blades over time. From the analytical result, the relationship between the stress distribution in the blades and the rotor velocity is got to be used as a reference for future wind turbine structural optimization.*
keywords *: transient flow field analysis, upwind wind turbine, horizontal axis, ANSYS.*

I. Introduction

The earth is along with the global climate vicissitude and the petrochemical energy is dried up gradually. The renewable and polluted lowly energy is subject to takes seriously, especially in February, 2005 Kyoto Protocol becomes effective, makes the explicit agreement to the greenhouse gas emissions decrement. In each kind of emerging energy, the wind turbine generator most has one of prospects for development renewable energy sources. In the past 10 years, installed global wind turbine capacity is 6,100 MW by 1996, around the end of 2008 it grows to 120,791 MW. From 1997 to 2008, installed global wind turbine capacity had increased by 35% annually, and growth of installed capacity from 1,280 MW to the end of 2008 of 27,056 MW, average annual growth rate is about about 29% [1].

Wind turbine is a mechanism that change the wind's kinetic energy into electrical energy of the rotating machinery, it is necessary to mention the theory proposed by the German aerodynamicists Albert Betz [2], according to Betz assumptions Ideally, to calculate the horizontal axis wind turbine, the maximum turbine coefficient (CP) is about 0.59, the energy available to wind generators is around 60%, but Betz flow model discussed only consider the axial flow without considering the wake rotation. Then the theory proposed by scholars Schmitz [3] considered the wind turbine swirl losses. Ji-Hang Luo [4] takes the rotor blades with three different parts of NACA airfoil as a reference, and uses the main model of commercially available NORDEX plant's N-50 800kW wind turbines as a simulation object. By using of STAR-CD CFD software for simulation, he compares the wind power, flow and torque under different available wind speeds to find the better airfoil. Cheng-Han Xie [5]carry out a simulation for the vertical-axis Giromail wind turbine, through experiments, multi-pipe flow model and the software FLUENT to explore the start capacity and aerodynamic properties.

Since the operation of wind turbines, mainly by aerodynamic effects of wind rotor blades rotate, thereby driving the generator inside the cabin to produce electricity. For the study of wind turbine structure, wind load caused by the importance of structure is evident. This feature is that the use of the wind turbine simulation model to establish the flow field domain model, simulate the operation of wind turbine rotor when the wind load.

II. Shape design and flow field analysis

2.1 Wind turbine structure

This paper uses the horizontal axis upwind turbine as the design model. Wind turbine is commonly classified as the horizontal axis type and vertical axis type. Among the horizontal axial wind turbine, there is a more detailed classification which includes the upper-wind type and lower-wind type. According to the wind direction, the rotor rotating against the wind before the tower bracket is called as upwind turbine, shape information as shown in Fig.1. This model is made up of blades, generators, hub, nacelle and tower shown in Fig.2. Upwind-type wind turbine model uses gearless direct-drive design, this type is usually taken an external cooling generator with a fin shape, back the nacelle is laid in the back as a short axis pattern. The shape appears to be more compact.

Fig. 1 5MW shape of horizontal axial upwind wind turbine

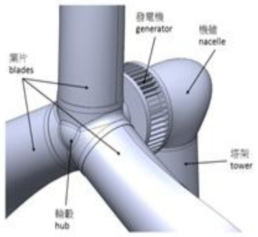

Fig. 2 5MW components of the horizontal axial upwind wind turbine

The diameter of Wind turbine rotor is 112.18 meters, the length of leaves is 54.5 meters, the height of hub is 84.05 meters, the tower owns a 84 meters height and conical shape, whose minimum and maximum diameter are 3.4 meters, 6 meters respectively, the basic specifications shown in Table 1. The angle between blades and rotor plane calls pitch angle or rotation angle, shown in Fig.3, the pitch angle used in this study is 0 °.

Tab. 1 Basic specification

Rotor Position	Upwind
Rated Turbine	5 (MW)
Rotor Diameter	112.18 (m)
Hub Height	84.05 (m)
Tower Diameter	3.4～6 (m)

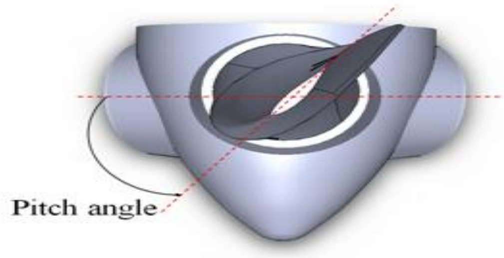

Fig.3 Pitch angle

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2.2 Flow field region and its size

The flow analysis of 5MW wind turbines includes two different fields which are outer flow field and the rotor flow field, the related calculation area is shown in Fig. 4. The diameter of turbine blade is D=120m, thickness is 6m. The total length of outer field is assigned to be 7D. The distance behind the blade to the rear edge is 4D. The distance from the side edge of the blade the side edge of the outer field is 2.5D. The height of the flow field is assigned to be 2D.

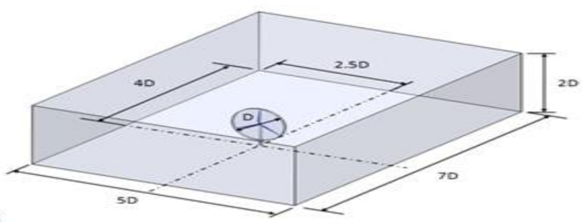

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Fig.4 calculated flow area and its size

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2.3 Wind turbine and flow field meshing

Mesh method uses the Advancing Front method, which is non-structural mesh method suitable for complex geometric shape, and built some denser mesh layers around the physical boundary.

The meshed model owns a total of 633,854 nodes and 3,674,692 elements, as shown in Tab.2. Element pattern is four faces cone, outer flow field and wind turbine mesh results are shown in Fig.5 and Fig. 6.

Tab.2 nodes and element number

Total number of nodes	633854
Total number of elements	3674692

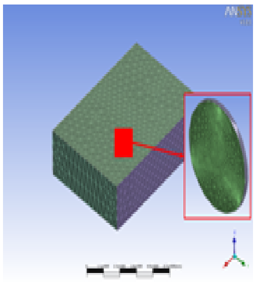

Fig.5 out flow mesh result

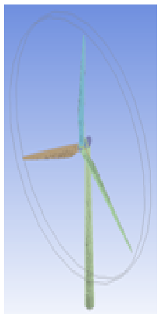

Fig.6 wind turbine mesh result

2.4 Boundary condition set

The boundary conditions are set by using the arrow symbol marking, shown in Fig.7. Black arrow symbol is defined as Inlet, which means the entrance boundary prohibiting backflow occurrence, and set the axial velocity as flow entrance velocity. Blue bi-directional arrow symbol is defined as Opening that sets the relative pressure with the outside world is 0. The boundary conditions on blades, surface, wheel, cabin and tower wall is set the wall boundary conditions which means non-sticky (Smooth Wall) and has a non-penetrating. Fluid flows through the wall must be satisfied no slip condition, which means the fluid velocity on the wall is equal to the speed of the wall.

The air flow conditions of 25℃, the air flow is single-phase flow regardless of sand, water and other multiphase flow conditions, material parameters are given by the software and keep constant. Assume that all processes in the solution process are the adiabatic process that means not considering heat conduction and solar radiation and so on.

The simulation time is 90 seconds analyzing Inlet axial velocity on the boundary and the rotor speed changing over time, the relationship between the inlet wind velocity and the time is shown in Fig.8, the relationship between rotor speed and time is indicated in Fig.9, the purpose is to control the speed of wind turbine changing over time. The maximum rotor speed of Upwind turbine is 14.093 RPM (at 34 seconds) and the minimum value is 13.633 RPM (in 75 seconds), the difference between them is 3.26%.

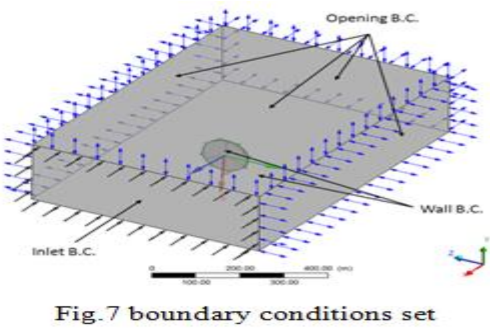

Fig.7 boundary conditions set

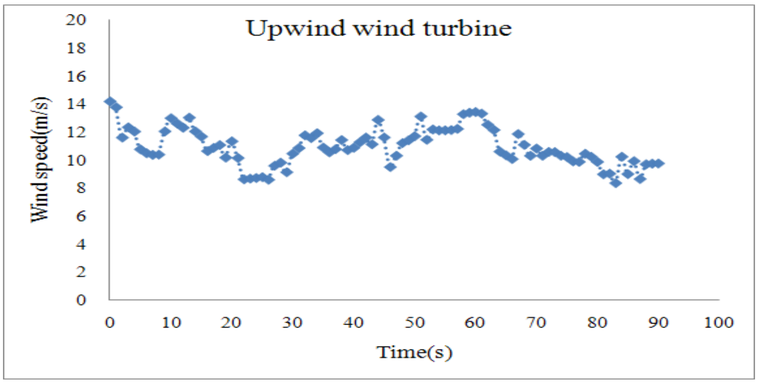

Fig.8 wind turbine inlet velocity vs. time graph

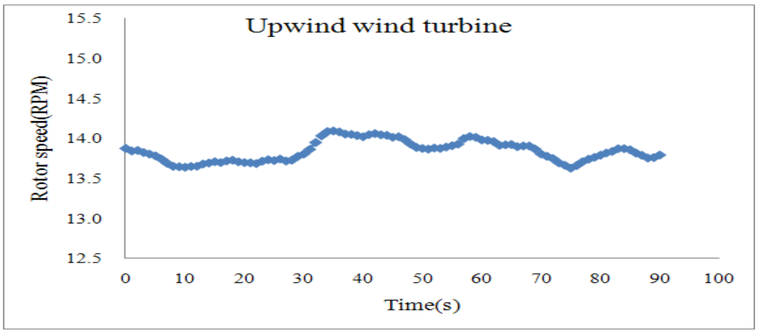

Fig.9 wind turbine rotating velocity vs. time graph

2.5 Coordinate system

Load data is output based on the generalized coordinate system, because the related results are changing in different coordinate system, CFX software, data output, you need to pay special attention to the case of coordinate system, the following are the output of the coordinate system load that Figure 10, according to this coordinate system, the output force and torque. Post-processing output setting, where outputs were set by calculating the load force and torque, the load position selector wheel (that is, the model of the three wind turbine blades and hub), and direction of the axis of the output, respectively X, Y, Z three axis, Figure 11, Figure 12.

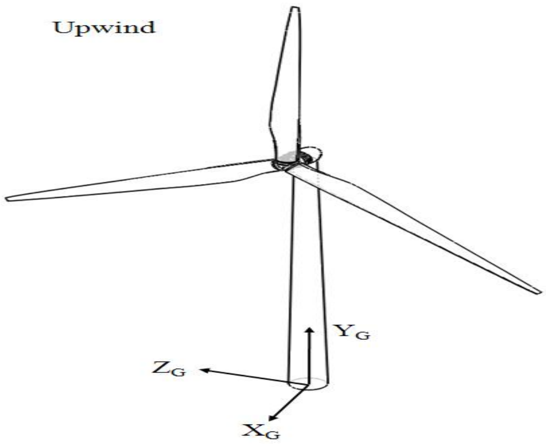

Fig.10 output coordinate system

Gust load data results

Upwind wind turbine data results are shown from Fig.13 to Fig.18. Data capture location is on the blades of wind turbine rotor, respectively for the X axis, Y axis and Z axis, data capture target is force and torque. from the results of Upwind wind turbine model, it can be found maximum force is 630641 (N), maximum torque M is 5.53 × 107 (N · m),the maximum value occurs at the 34th seconds of wind turbine operation, coinciding with the maximum value of the rotor speed changing over time, through comparing the results of Fig.9 and Fig.13, Fig.9 and Fig.18, it can be observed the greater the rotor speed, the larger the load on the blades.

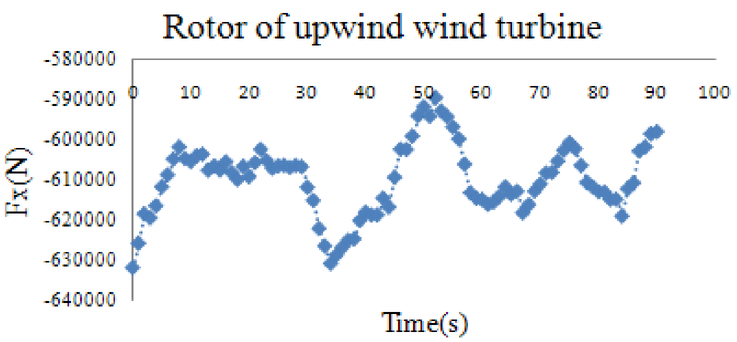

Fig.13 X-axis force vs. time graph

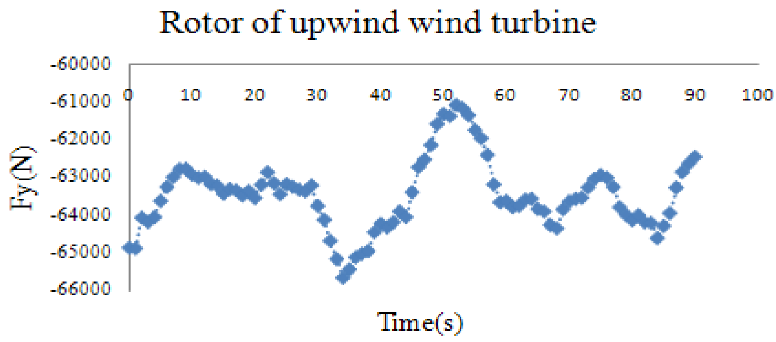

Fig.14 Y-axis force vs. time graph

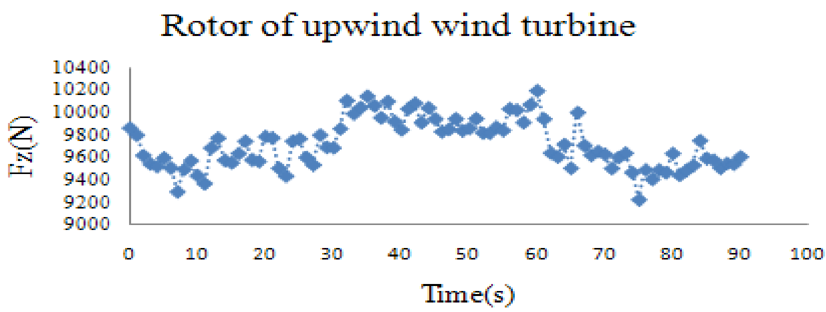

Fig.15 Z-axis force vs. time graph

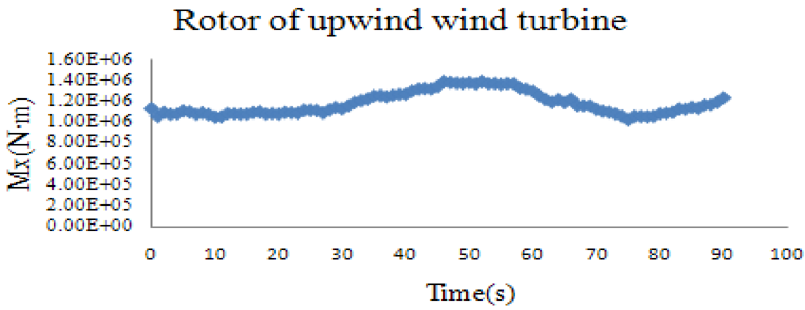

Fig.16 X-axis torque vs. time graph

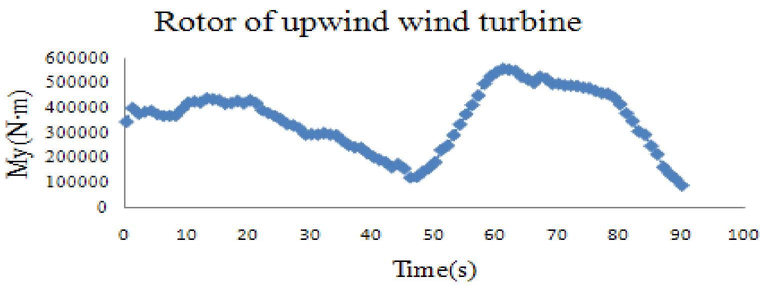

Fig.17 Y-axis torque vs. time graph

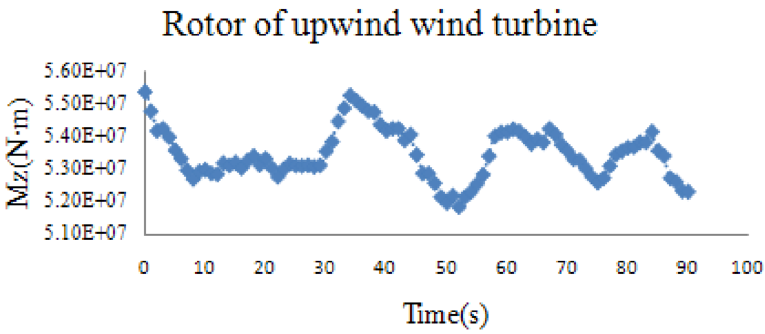

Fig.18 Z-axis torque vs. time graph

III. CONCLUSION

Through the results on load diagram at a few high points in time, it can be found that the greater the rotor speed, the larger the load on the blades. In fact the wind machine in the load situation is very complicated, and the actual wind conditions and wind machines are non-stable, so in the simulation of this paper the ideal wind conditions are assumed. As for the analysis model, the pitch angle of the blade is not considered. In addition, the impact of surface roughness to the wind change, heat conduction and multiphase flow problems are available for further consideration.

ACKNOWLEDGEMENTS

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