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Buffeting Response of Ultimate Loaded NREL 5MW Wind Turbine Blade using 3-dimensional CFD

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ABSTRACT

Wind turbine blades should be designed to maximize the generated torque in the rated wind of the turbine. Although many studies related to the power generation efficiency have been performed but only a few papers have been studied on the safety concept of the structure in the high speed wind. This study develops Computational Fluid Dynamics code and analyzes ultimate wind loads and member forces transferred to the support structure. The structural vibration properties could be varied with respect to the turbulence intensity of wind. This study performed wind-structure interaction CFD analysis of whole wind turbine structure model and analyzes ambient wind flow and structural vibrations.

1. INTRODUCTION

The increasing needs for the environmental safety and the rising apprehension for the nuclear power generation spur the development of new type of renewable energy. Considering the feasibility and the potential wind power will be the great alternative and the related fundamental study and technology have been actively conducted. Furthermore the offshore wind power has high generation efficiency and convenience to arrange site, it is focused in the maritime countries.

The generation efficiency of wind turbine is proportionate to the swept area of the blade. The efficiency of wind turbine can be increased with increasing size. However, a large size of wind turbine may be faced with aerodynamic problems, which has not been occurred to the existing wind turbines (i.e., small size ones). With such reasons, stabilization of the structure to wind is necessary. Previous studies on aeronautical, electrical, and mechanical area are related only to the efficiency of power generation. As the growth of the size, the wind turbine is becoming infra-structure but there are few studies related to the safety in the high range of wind velocity exceed the rated wind. This study was conducted to analyze buffeting responses, which are major

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aerodynamic phenomenon, of NREL 5MW baseline turbine using computational fluid dynamics.

Site monitoring, Wind tunnel test and CFD are main methods to analyze the aerodynamic properties of wind turbine. Site monitoring is most reliable method but it needs existing structure and couldn't manipulate the wind velocity. Wind tunnel test is limited also to analyze the stability, it requires a special wind tunnel and is difficult to setup a model has equal dynamic properties with the real structure. On the contrary, CFD could analyze large structure without these restrictions.

Early CFD studies developed for estimating lift force of airfoil sections in the region of aeronautics. Since the development of computing equipment and the numerical direct solutions to the governing equation of fluid, a great deal of research is being carried out to analyze aerodynamic properties of wind turbine structures. In early 2000, CFD was mainly two-dimensional analysis to calculate the sectional aerodynamic properties (i.e., static force coefficients and flutter derivatives). With advancements in parallel and supercomputing technology, overall three-dimensional responses can be analyzed using CFD. Bazilevs(2010)(Bazilevs 2011) analyzed wind-structure interaction of NREL 5MW baseline structure using NURBS-based isogeometric analysis. Yuwei(2012)(Li 2012) studied wind turbine structure that has 10m bladed using Detached Eddy Simulation. In most cases responses has been conducted under the rated wind speed of wind turbine. The objective of this paper is to present three-dimensional CFD responses of NREL 5MW baseline wind turbine under the 50-year return period wind velocity and analyze aerodynamic properties of the structure.

This study developed a FEM software(Byeong-Cheol 2013) that equipped an open source library, Elmer CFD. In this algorithm, moving mesh and ALE method is adopted to perform aero-elastic analysis and wind turbulence applied to the boundary condition of the model is generated from Kaimal spectrum. This software has been compiled and executed at KISTI Tachyon II parallel system.

2. NUMERICAL METHODS

2.1 Governing Equations

In most CFD algorithms, the order of shape function of pressure is set to a low degree than velocity's one to ensure the convergence in the process of solving discretized Navier-Stokes equations. This study could stabilize the solution while using equal degree of order to the shape functions of pressure and velocity, by introducing SU/PG method which adds a square term of governing equation's residual to Galerkin weighted function. The governing equation discretized by Glaerkin Least Square method are shown at Eq. (1), (2).

$$-\left[L\right]^{T}\mathbf{u}=\mathbf{0} \tag{1}$$

$$\left[M_{F}\right]\dot{\mathbf{u}}+\left[C_{F}\right]\mathbf{u}+\left[K_{F}\right]\mathbf{u}-\left[L\right]\mathbf{P}=\mathbf{F}_{F} \tag{2}$$

Where $\left[M_{F}\right]$ is the mass matrix of the elements, $\left[C_{F}\right]$ is non-linear asymmetric matrix that represents the convection term, $\left[K_{F}\right]$ is linear symmetric matrix proportional to the viscosity. $k-\varepsilon$ model that representative of RANS model was applied to the turbulence model.

3. CFD Analysis

3.1 Structure Specification

NREL 5MW baseline wind turbine were selected to analyze structural response to the turbulence in high speed wind. The structure has lots of released experimental data from many researchers and this study verified the CFD results by comparing to the previous studies.

The NREL 5MW reference structure is 70m in height from the top of TP to the center of the rotor blade which length from the center to the tip is 63m. The diameter of tower is linearly varied from 5.3m bottom to 4.0m top, and the height, width and length of nacelle are assumed 5m, 5m and 15m, respectively. The geometrical shape of blade is consisted with cylinder, DU airfoil and NACA airfoil and maximum width is 4.557m, tip width is 1.419m, maximum chord is 1.843m. The total weight of the blade is 18.0tonf, moment inertia is 13206.7ton-m2, radiation of gyration is 27.1m. Specification of mass and stiffness is summarized in Table 1, 2.

Table 1 Definition of blade shape

	1	2	3	4	5	6	7	8	9	10
Distance along blade	0	5.6	11.75	19.95	28.15	36.35	44.55	52.75	58.9	61.633
Distance along pitch axis	0	5.6	11.75	19.95	28.15	36.35	44.55	52.75	58.9	61.633
Chord	3.542	3.854	4.557	4.458	4.007	3.502	3.01	2.518	2.086	1.419
Aerodynamic twist	13.308	13.308	13.308	10.162	7.795	5.361	3.125	1.526	0.37	0.106
Thickness	100	100	40	35	25	21	18	18	18	18
Neutral axis(x)	0	0	0	0	0	0	0	0	0	0
Neutral axis(y)	0	0	0	0	0	0	0	0	0	0
Neutral axis, local(x')	0	0	0	0	0	0	0	0	0	0
Neutral axis, local(y')	25	25	25	25	25	25	25	25	25	25
Foil section	1	1	2	3	4	5	6	6	6	6
Moving/fixed	Move	Move	Move	Move	Move	Move	Move	Move	Move	Move

Table 2 Definition of blade mass and stiffness

	Unit	1	2	3	4	5	6	7	8	9	10
distance along pitch axis			5.6	11.75	19.95	28.15	36.35	44.55	52.75	58.9	61.633
Center of mass(x')	%	0	0	0	0	0	0	0	0	0	0
Center of mass(y')	%	25	30.7382	41.1493	47.80838	40.09008	39.00737	50.3895	46.15755	40.3604	32.22126
Mass axis orientation	deg	13.308	13.308	13.308	10.162	7.795	5.361	3.125	1.526	0.37	0.106
Mass/unit length	kg/m	678.935	607.2506	425.8459	338.1669	293.0208	234.8319	160.5537	102.8078	67.7688	46.25769
Polar inertia/unit length	kgm	0	0	0	0	0	0	0	0	0	0
Radii of gyration ratio		1	1	0.4	0.35	0.25	0.21	0.18	0.18	0.18	0.18
Principal axis orientation	deg	13.308	13.308	13.308	10.162	7.795	5.361	3.125	1.526	0.37	0.106
Bending stiffness about xp	Nm^2	1.81E+10	1.54E+10	7.17E+09	4.47E+09	3.38E+09	2.17E+09	1.11E+09	4.85E+08	2.74E+08	8.73E+07
Bending stiffness about yp	Nm^2	1.81E+10	1.12E+10	4.65E+09	2.02E+09	1.05E+09	3.78E+08	1.18E+08	5.50E+07	2.54E+07	7887502

3.2 2-Dimensional CFD

Aerostatic coefficients of the airfoils measured from experimental methods are shown in Fig. 1. Compare the coefficients to the two-dimensional CFD results. Except some ranges exceed 40 degrees angle of attack, the CFD results are corresponded well with the experimental one. Furthermore, overall structure responses calculated by Blade Element Momentum Theory substituting aero-static properties calculated from two-dimensional CFD compared with the response of the three-dimensional CFD.

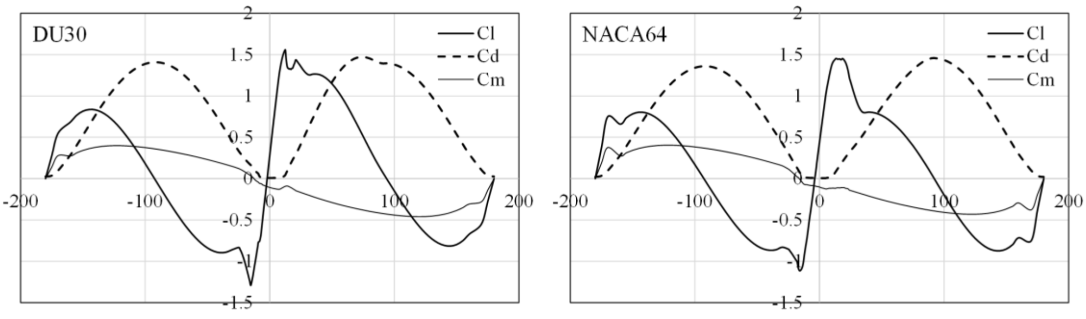


Fig. 1 Aerostatic forces of NREL 5MW blade sections(Jonkman 2009)

3.3 3-Dimensional CFD

Generated turbulent wind velocity as a boundary condition of CFD model is shown as Fig. 2. The time history records of wind velocity substituted at the inlet boundary conditions are generated apart 10m interval along the lateral line to considering time and space correlations, the other non-generated points used linear interpolated ones. The blade is modeled as Fig. 3 then the mesh of model was configured as Fig. 4. Analyzed displacement responses are shown in Fig. 5.

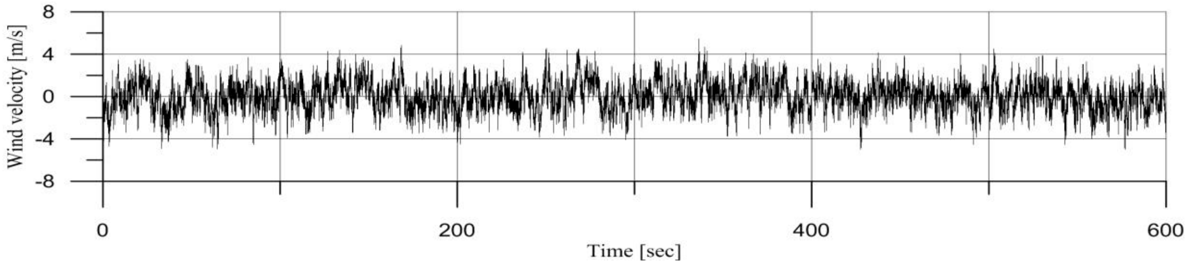


Fig. 2 Aerostatic forces of NREL 5MW blade sections(Jonkman 2009)

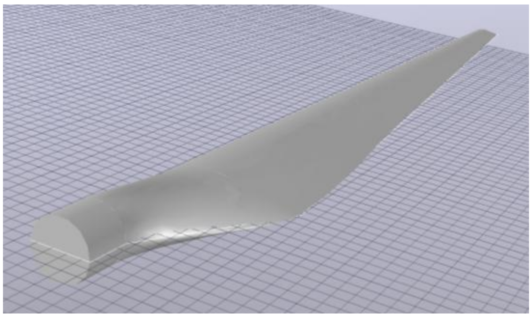


Fig. 3 Geometry of blade

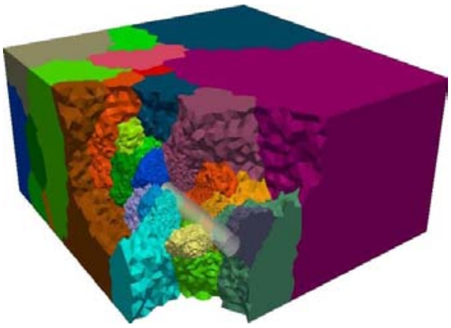
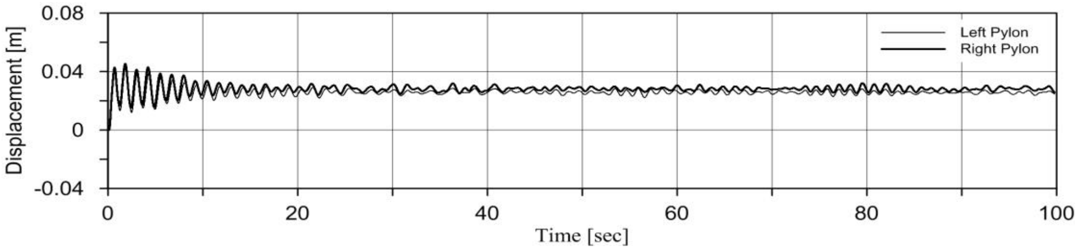
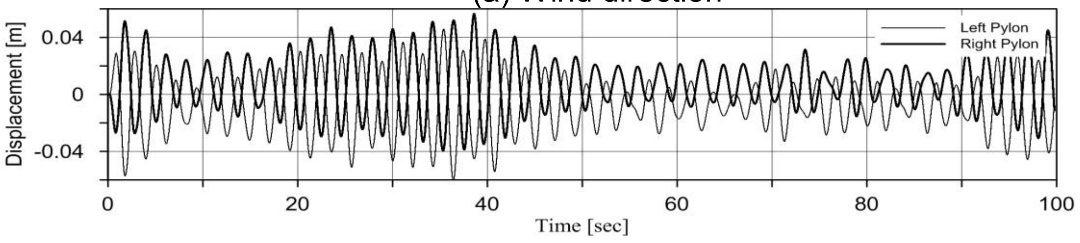


Fig. 4 Mesh division for parallel analysis

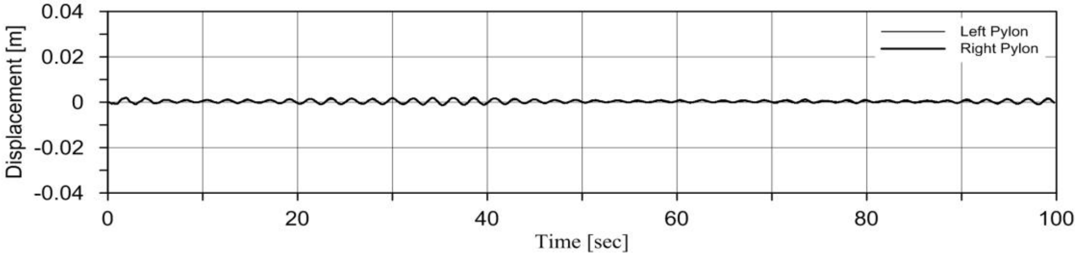


(a) Wind direction



(b) Lateral

Fig. 5 Buffeting response of the blade tip(Jonkman 2009) (1/2)



(c) Vertical

Fig. 5 Buffeting response of the blade tip(Jonkman 2009) (2/2)

3. Conclusions

The three-dimensional CFD analysis of wind power generation structure considering wind-structure interaction is in progress, and from the partial results show well agreement with respect to the experimental results. Further study must be concluded wind induced responses for the whole structure model and analyzes the load transmitted to the support structure. (Bazilevs 2011)

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