The 2012 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM' 12)
Seoul, Korea, August 26-30, 2012

Dynamic Analysis of 5-MW Onshore Wind Turbine

Kun-Woo Kim[2], *Dae-Guen Lim[2] and Wan-Suk Yoo[1]

[1], [2] *Department of Mechanical Engineering, Pusan National University, Busan 609-735, Korea*
[1] *wsyoo@pusan.ac.kr*

ABSTRACT

The objective of this paper is to analyze a dynamic response of a 5-MW onshore wind turbine. The 5-MW wind turbine that consists of a tower, a nacelle, a hub and three blades is constructed using a multibody based technique. The tower and blades are regarded as flexible body considering nodal deformation vector, and the others are regarded as rigid body with six degrees of freedom. It is assumed that external forces applied to the system are only aero-elastic force caused by constant wind velocity and gravitational force. A thrust and tangential force on blades are calculated by using the blade element momentum theory.

1. INTRODUCTION

Wind power generation had been one of the most famous resources to get an energy together with solar and solar-light power generation. Especially, some of the countries which are China, the United States, and Germany, etc. spur on the development of new technology for wind turbine. Since around 1980s, wind power generation has became larger and larger owing to technological advancement. In spite of the advancement, it is necessarily to expect dynamic features of components such as tower, nacelle, hub and blades to secure stability and durability. Thus, in this paper, dynamic characteristics for 5-MW onshore wind turbine are analyzed with multibody based modeling (Jonkman 2009). In chapter 2, basic equations are explained to construct a wind turbine system using RNCF(relative nodal coordinate formulation) method and to give aero-elastic force to the system. In chapter 3, it is included some kinds of analysis results such as strain and stress on the top of tower. Finally, in chapter 4, conclusions of this study are drawn.

2. EQUATIONS FOR 5-MW WIND TURBINE

There are two types of techniques for constructing the components of wind turbine system. The first one is related to rigid body and the second type is for flexible body. To

[1] Professor
[2] Graduate Student

model hub and nacelle, equations for rigid body are needed, but equations for flexible body are required to model tower and blades.

2.1. Rigid Body

Nacelle and Hub can be modeled with the type of rigid body because the deformable rate of such bodies is too small. As shown in Fig. 1, the position, velocity and acceleration vectors of an arbitrary point on the body can be written as Eqs. (1-3) (Shabana 2010).

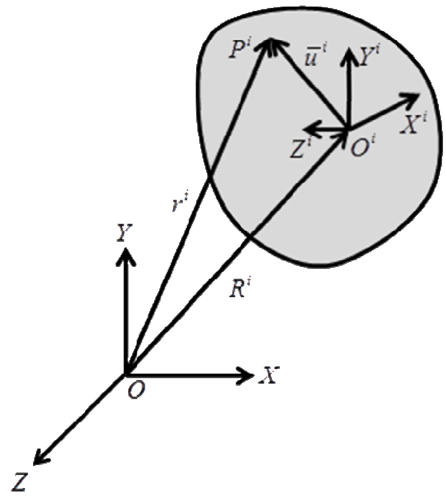

Fig. 1 Rigid body coordinates

$$r^i = R^i + A^i\bar{u}^i \tag{1}$$

$$\dot{r}^i = \dot{R}^i - A^i\tilde{\bar{u}}^i\bar{G}^i\dot{\theta}^i \tag{2}$$

$$\ddot{r}^i = \ddot{R}^i - A^i\tilde{\bar{u}}^i\bar{G}^i\ddot{\theta}^i - A^i\tilde{\bar{u}}^i\dot{\bar{G}}^i\dot{\theta}^i + A^i\tilde{\bar{\omega}}^i\tilde{\bar{\omega}}^i\bar{u}^i \tag{3}$$

where r^{ij} is the global position vector of the origin of the body reference $X^iY^iZ^i$, A^i is the transformation matrix from the body coordinate system to the global XYZ system, and $\bar{u}^i$ is the position vector of the arbitrary point with respect to the body coordinate system. The angular velocity vector $\bar{\omega}^i$ defined in the body coordinate system and $\bar{G}^i$ is a matrix that describes the relationship between the angular velocity and Euler angles $\dot{\theta}^i$. Adopting the vectors in the principle of virtual work as Eq. (4), the equation of motion for rigid body can be derived.

$$\delta W^i_{inertia} = \int_{V_i} \rho_i \delta r^{iT} \ddot{r}^i dV^i \tag{4}$$

If the origin of the body coordinate system is rigidly attached to the center of mass, the equation of motion can be simplified because there is no inertia coupling between the translation and the rotation of the rigid body.

2.2. Flexible Body

Tower and blades are assumed as flexible body because the ratio of length to area is too large. As shown in Fig. 2, the position, velocity and acceleration vectors for the deformable body can be written as Eqs. (5-7) (Shabana 2005).

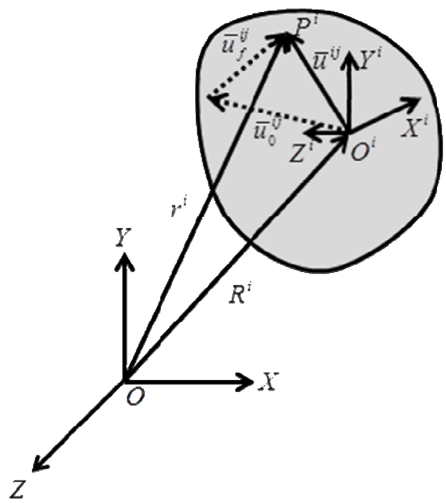

Fig. 2 Deformable body coordinates

$$r^{ij} = R^i + A^i \bar{u}^{ij} \tag{5}$$

$$\dot{r}^{ij} = \dot{R}^i - A^i \tilde{\bar{u}}^{ij} \bar{G}^i \dot{\theta}^i + A^i N^{ij} B_2^i \dot{q}_f^i \tag{6}$$

$$\ddot{r}^{ij} = \ddot{R}^i - A^i \tilde{\bar{u}}^{ij} \bar{G}^i \ddot{\theta}^i + A^i N^{ij} B_2^i \ddot{q}_f^i - A^i \tilde{\bar{u}}^{ij} \dot{\bar{G}}^i \dot{\theta}^i + A^i \tilde{\bar{\omega}}^i \tilde{\bar{\omega}}^i \bar{u}^i + 2A^i \tilde{\bar{\omega}}^i S^{ij} B_1^{ij} B_2^i \dot{q}_f^i \tag{7}$$

where r^{ij} defines the position vector of an arbitrary point on element j of body i, N^{ij} is the space-dependent matrix, S^{ij} is the space-dependent shape function defined in the intermediate coordinate system and B_1^{ij} and B_2^i are the Boolean matrices. Adopting the vectors in the principle of virtual work, the equation of motion for flexible body can be derived.

2.3. Blade Element Momentum Theory

Most commercial software such as GH Bladed, HAWC, HAWC2, BHAWC, FAST, ADAMS, Flex5(Vestas A/s), Flex5 (DONG) and Flex5 (SWE) adopt BEM (blade element momentum) theory. Although BEM (blade element momentum) theory is one of the most oldest and commonly used methods, it has some limitations; the calculations are static, it breaks down when the blades experience large deflections out of the plane and the forces acting on the blade element are essentially two-dimensional (Moriarty 2005). In spite of such limitations, in this paper, blade element momentum theory is adopted to calculate aero-elastic force on the wind turbine system.

3. DYNAMIC RESPONSES FOR 5-MW WIND TURBINE

The properties to perform dynamic simulation are defined in the reference of Jonkman et. al. (2009). Considering the states that the hub is rotated with 12.1 rpm and the wind speed is 11.4 m/s, normal strain and Von Mises stress can be represented as Fig. 3. As shown in Fig. 3, it is known that the normal strain on the top of tower is in the range between 0 and -1.0E+06. Also, it is seen that the tower is stable in the current states because the maximum Von Mises stress is 16.93 MPa which is much less than the yield stress of steel (about 120 ~ 140 MPa).

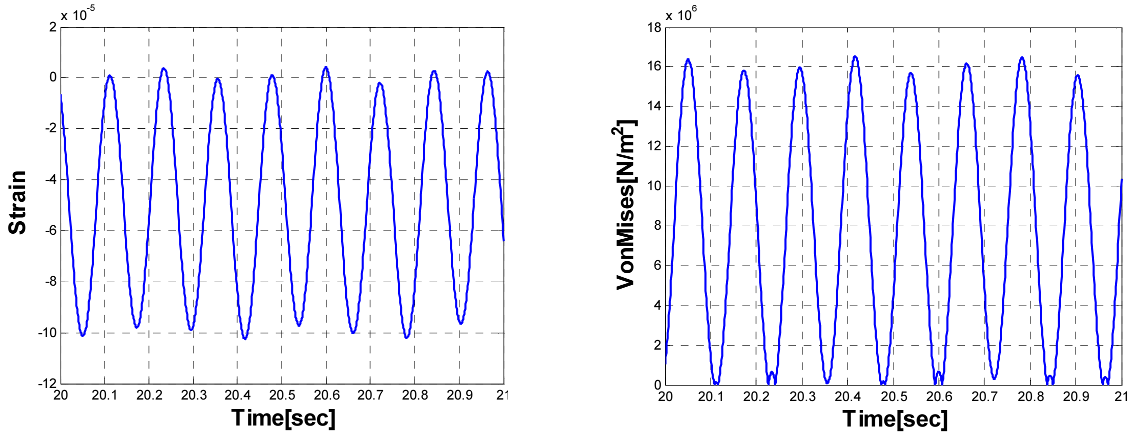

Fig. 3 Normal strain and Von Mises stress on the top of tower

4. CONCLUSION

Dynamic responses for 5-MW wind turbine are analyzed with multibody based technique. Hub and Nacelle are assumed to rigid body and tower and blades are modeled to flexible body using RNCF. According to the results related to normal strain and Von Mises stress, it can be concluded that tower can endure the imposed conditions that the hub is rotated with 12.1 rpm and the wind speed is 11.4 m/s.

ACKNOLEDGEMENT

This work was supported by the New & Renewable Energy of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 20113020020010).

REFERENCES

Jonkman, J., Butterfield, S., Musial, W., and Scott, S. (2009), "Definition of a 5-MW Reference Wind Turbine for Offshore System Development," NREL/TP-500-38060, National Renewable Energy Laboratory.
Shabana, A. A. (2010), Computational Dynamics 3rd Ed., Wiley.
Shabana, A. A. (2005), Dynamics of Multibody Systems., Cambridge.
Moriarty, P. J., and Hansen, A. C. (2005), "AeroDyn Theory Manual," NREL/EL-500-36881, National Renewable Energy Laboratory.