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Basic Design and Finite Element Analysis of Substructure of 2.5MW Floating-type Offshore Wind Turbine

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ABSTRACT

In this study, the basic design of 2.5MW spar-type floating substructure for deep water offshore wind turbine is presented by upper and lower part respectively. Upper part is assigned to hub and nacelle in the basic design of blade which design parameter is blade's thickness, width, length, weight, and wing section. Lower part is designed to buoy structure and mooring system which is buoy's thickness, length, and weight. The considered platform configuration of the present offshore wind turbine model is the typical spar-buoy type. This paper addresses the design parameter which blade design is secured to energy content, and mooring system is obtained by catenary equation. In order to verify the reliability, modal analysis is performed.

INTRODUCTION

As environmental problems become a serious issue worldwide, the interest of energy increases rapidly, the focus is coming to fix in the clean energy. With alternative energy among new renewable resource, wind energy has been grown up until now and steadily is come. As capacity increases, noise and scale will become larger but offshore wind turbine system is coming to important than the onshore wind turbine system. To complement the weak points which are discovered from the existing onshore wind turbine system and for a more generating capacity, the wind power generator is established with the offshore floating substructure in deep water(WEC 2009).

As offshore wind power generator can make use of wide offshore areas, it can be an alternative that overcomes the spatial limitations of onshore wind power generation.

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There is also the added benefit that the load of the offshore wind turbine can be reduced because a high and certain level of wind speed is maintained and there is little turbulent flow(Musial 2006**)**. In this paper, the design parameter will be established through the basic design concept of 2.5MW spar-type floating substructure. Furthermore structural analysis program Nastran FX(Midas IT 2009) is used to compare the theory. Minimum thickness of buoy's structure is obtained by buckling analysis, and upper part's nacelle, hub, and blade is designed by considering of the whole center of gravity. Specification of spar-type floating substructure for deep water offshore wind turbine is defined by design variables.

SPECIFICATION AND BASIC DESIDN OF SPAR-TYPE FLOATING SUBSTRUCTURE

The offshore wind turbine is classified to 2-types which fixed-type and floating-type by the installation method. Fixed-type substructure is piled seabed like onshore substructure, and floating-type which floating in the sea controls the motion of the body by mooring system. In the early days of constructing offshore wind parks, the fixed-type was most often used, but it had the drawback that as the depth of the water increased the construction costs of the fixed-type substructure rapidly increased. As a result, to design the basic concept of floating-type wind turbine in this research, it is designed upper and lower part separately. Upper part is classified by the blade, hub, and nacelle. Lower part is classified by the buoy body and mooring system. In the basic design of upper part, blade design is performed on wing section, dimension, and weight, besides tower, hub, nacelle is on shape, dimension, and weight, components of its part are designed by the center of gravity considered. Nacelle is designed outer surface only. To basic design of the floating offshore substructure for deep water, Fig. 1 shows upper part's component, dimension, and load case. L_B is blade's length, a is distance between hub's center of gravity and whole center of gravity, b is distance between nacelle's center of gravity and whole center of gravity L_L is lower part's length, D_T is lower part's diameter and thickness, W_B is blade's weight, W_N is nacelle's weight.

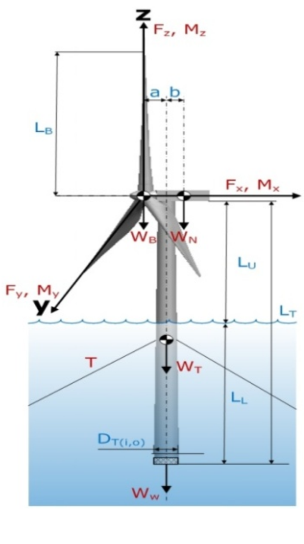


Fig. 1 Schematic of offshore wind turbine

DESIGN OF UPPER PART

In the blade design, blade length could be obtained by scale parameter, shape parameter, rated wind speed, operating wind speed, rated power, blade number, and mean wind speed using weibull distribution of wind power generation(shahidehpour 2009). Scale parameter(C) is the meaning of standard wind power, shape parameter(K) is the numerical data of wind probability distributions regarded as standards wind power. Where, V is wind mean speed. Weibull distribution is suitable to use life distribution of wind turbine in probability distribution. Using specification of wind turbine, blade length is decided by Fig. 2.

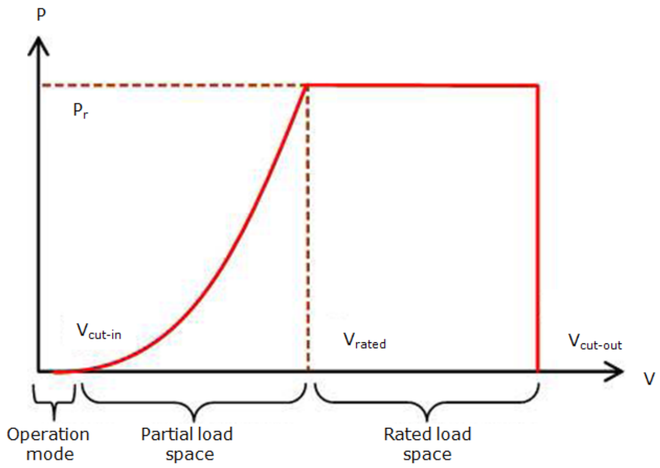


Fig. 2 Weibull distribution of wind power generation

Where, rated wind speed($V_{cut\text{-}in}$)is a smallest wind speed will be able to occur a designed power in the wind power motor, and operating wind speed(V_{rated})is a wind speed will be able to occur a designed power without help of a wind power motor, and cut-out wind speed($V_{cut\text{-}out}$)is a wind limit speed passes through the rated wind speed. Weibull distribution function currently evaluates the density of area by wind load is a method which is used plentifully because of its pliability and simplicity. 2.5MW-class wind power generator's specification using most popular is applied in rated wind speed, operating wind speed, cut-out wind speed, and the number of blade(Hwang 2010). In addition, blade length is secured by energy quantity of wind turbine generator.

The energy quantity of wind turbine generator's equation is as follows (shahidehpour 2009);

$$E_{1R} = \frac{P_R T}{V_R^n - V_I^n} \int_{V_I}^{V_R} (V^n - V_I^n) \frac{k}{c} \left(\frac{V}{c}\right)^{k-1} e^{-\left(\frac{V}{c}\right)^k} dV \tag{1}$$

$$E_{RO} = P_R T \int_{V_R}^{V_0} \frac{k}{c} \left(\frac{V}{c}\right)^{K-1} e^{-\left(\frac{V}{c}\right)^k} dV \tag{2}$$

$$E_T = E_{1R} + E_{RO} \tag{3}$$

Where, E_{1R} is the energy region of the below rated wind speed, E_{RO} is the energy region of the over rated wind speed, E_T is the total energy quantity, V_R is the rated wind speed 12m/s, V_I is the operating wind speed 3.5m/s, V_o is shut down wind speed 25m/s, P_R is the rated power 2.5MW, n is the number of blade 3, T is the mean wind speed 7.84m/s.

$$R = \sqrt{\frac{2E_T}{\eta_s \times \rho_a \times \pi \times (1.3V_M)^3 \times T}} \tag{4}$$

Where, R is the radius of rotor, in which rotor length is the gyration radius of wind power generator, η_s is the designed operating efficiency, ρ_a is the air density, V_M is the designed wind speed. As with the obtained blade's length, NACA type should be selected. NACA 64-518 type is selected considering lift coefficient, thickness ratio, and wing section type. Furthermore, thickness and width of blade could be selected by division of Station 1 ~ 10 if wing section type fixed in advance. In addition, blade length is obtained by 45m, nacelle and hub could be designed proportional to the blade's characteristic due to not precise modeling analysis performed, so those are modeled as the same shape and weight like general 2.5MW wind turbine generator(Hwang 2010). Proper tower is adopted as a reference of blade's length and geographical characteristics in spar-type floating substructure for deep water wind turbine generator.

DESIGN OF LOWER PART

When design the lower part in the basis of former design(upper part), it is classified 2 types. Consequently buoy body which considering buoyancy and ocean condition, and mooring cable which controlling the horizontal force and uniformity of floating substructure for deep water is classified. Where, the buoyancy is calculated in the basis of the weight of blade, hub, nacelle, and rotor as well as buoy body itself. So the basic design of buoy body is defined by the design variable which upper part's weight, lower part's weight, cable's weight, and buoy's thickness.

The calculation of buoy's weight and buoyancy showed as follows.

$$R_{BUOY} = [(L \times \pi \times r^2 \times \rho_a) - \{L \times \pi \times (r_o^2 - r_i^2)\} \times \rho_s] \times 9.81(m/s^2) \tag{5}$$

Where, R_{BOUY} is buoyancy, t is buoy's thickness, ρ_a is steel density. Then buoyancy could be achieved in 5120KN including buoy's weight itself.

Fig. 3 shows the FBD(Free Body Diagram) according to define the mooring's length and setting up a tension.

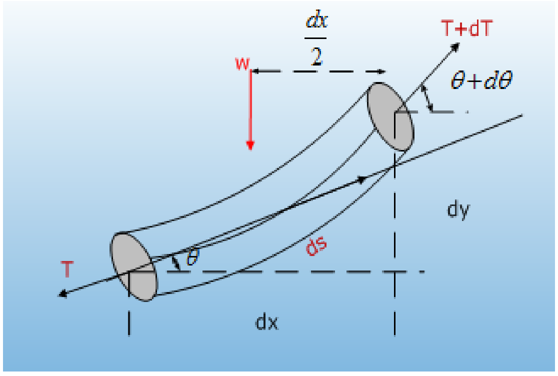


Fig. 3 Free body diagram of mooring rope

While specification of mooring rope is defined by external force and its length.

What is more, in the mooring rope's design, firstly after designed single unit mooring system and then complex composition system is established in the detailed design process, but this research defined the specification of mooring system by single unit due not to important for mooring system in this research. Then, the static equilibrium equation is defined using catenary equation.

To select the design variable of mooring rope, equilibrium equation of mooring rope is as follows:.

$$\sum F_x = 0; -T\cos\theta - (T + dT)\cos(\theta + d\theta) = 0 \tag{6}$$

$$\sum F_y = 0; -T\sin\theta - w_0 ds + (T + dT)(\sin\theta + \cos\theta d\theta) = 0 \tag{7}$$

$$\sum M = 0; w_0 ds\frac{dx}{2} + T\cos\theta dy + T\sin\theta dx = 0 \tag{8}$$

Where,T is tensile force, w_o is the mooring's unit weight, and H is the horizontal force. The position of mooring rope is selected by degree of mooring rope and weight per unit length.

Then rope's length could be calculated as follows:

$$dS = dx\int\sqrt{1 + (\frac{dy}{dx})^2} \tag{9}$$

Here, calculated rope's length is 566m. Consequently minimum effective thickness is achieved by 54mm on the condition of 65m height. Basic specification of upper and lower part shows Table 1.

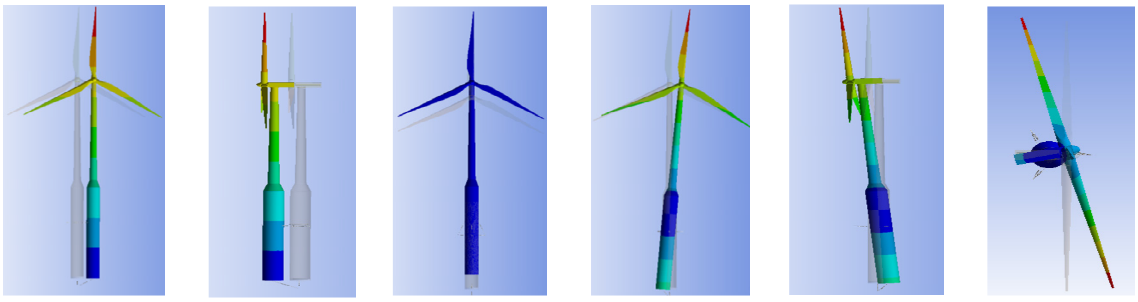
Table 1 Basic data of estimated model

Part	Material	Value
Nacelle	stainless steel	Height[m] : 3.2
		Width[m] :3.2
		Length[m] : 10
		Mass[ton] : 146
Tower	S355NL	Height[m] : 65
		Diameter Top[m] : 3
		Diameter Bottom[m] : 4.5
		Thickness Top[m] : 0.05
		Thickness Bottom[m] : 0.1
		Mass[ton] : 170
Plat-form	S355NL	Height[m] :65
		Diameter Top[m] : 4.5
		Diameter Middle[m] : 8
		Diameter Bottom[m] : 8
		Thickness Top[m] : 0.054
		Thickness Bottom[m] : 0.054
		Mass[ton] : 2,684
Rope	6x36ws+iwrc	Diameter[m] : 0.092
		Length[m] : 566
		Weight per length[N/m] : 300

VERIFICATION OF RELIABILITY

The model of the floating-type offshore wind turbine is analyzed by ANSYS(ANSYS Inc., 2011). In order to describe the behavior of the model, spring element which connected center of the gravity in the direction of 120 degree is used and controlled the horizontal displacement. And to consider the deep water condition, spring element which connected lower part of the model is used and controlled the vertical displacement. The stiffness of spring element is 100N/m. In contact conditions, friction coefficient of nacelle-hub is 0.06, nacelle-tower is 0.15, and blade-hub is welded. To verify the mode analysis, Block-Lanczos method(Son 2008) which is useful in large size and axi-symmetric flatform is used. Therefore, mode analysis of the spar-type is extracted by 6 mode case, and damping effect is disregarded due to not disperse the energy in case of steel structure conditions.

As a result, mode shape and natural frequency is follows.



Platform Sway Platform Surge Platform Heave Platform Roll Platform Pitch Platform Yaw

Fig. 4 Mode shapes

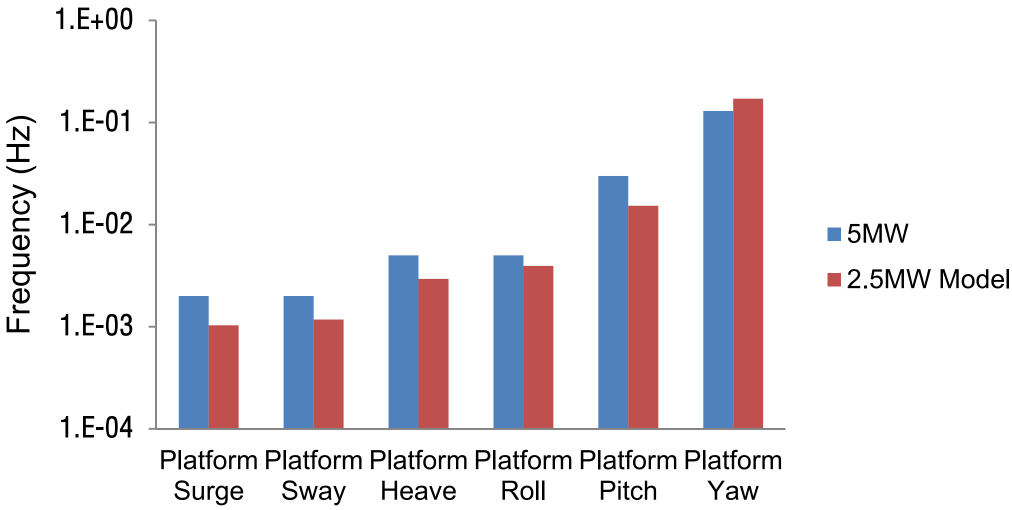


Fig. 5 comparison of natural frequencies for 2.5MW & 5MW floating offshore wind-turbine

Modal analysis was done in order to check the dynamic behavior of the floating-type wind turbine ranked at 5MW and to compare with the existing NREL Baseline model(Jonkman 2010). The comparison of the results confirmed that modal analysis using spring element is a good practical way of predicting the macroscopic dynamic behaviors of floating-type super-sized offshore wind turbines.

ACKNOWLEDGEMENT

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