Evaluation of influence on shape design of floating offshore wind turbine substructures

Siwon Jang, Soonsup Lee, Donghoon Kang and Jonghyun Lee *

Department of Ocean System Engineering, Gyeongsang National University, Tongyeong, 650-160, Korea

*Email: gnujhlee@gnu.ac.kr

Abstract. The increase of demand and the depletion of energy resources have led to a rising demand of renewable energy. Among them, wind turbine has been researched because of wide generality with high resource potential. Despite these advantages, onshore wind turbine has a spatial constraint. To solve these problems, offshore wind turbine has been researched and the installation area of onshore structures has been expanded to offshore field. The design of the substructure is one of the most important issues in case of motion characteristics in the ocean rather than on the coast. Tri-pod type is attracting attention because it is easy to manufacture and efficient to reduce environmental load. However, the motion characteristics of these types of structures have not been clarified yet and are currently studied. In order to improve the float performance, it is necessary to apply the optimal float design such as size, weight, water plane area, and mooring to each design. In this study, we have described tri-pod type model and evaluated the model test to find the effects of the ratio of the diameter to draft in dynamic motions of the structures on the basis of the floating column design. Since each design variables are determined, experimental RAO results have analysed through motion analysis of 6 degrees of freedom.

1. Introduction

The increase of demand and the depletion of energy resources have led to a rising demand of renewable energy. Among them, wind turbine has been researched because of wide generality with high resource potential [1]. Despite these advantages, onshore wind turbine has a spatial constraint. To solve these problems, offshore wind turbine has been researched and the installation area of onshore structures has been expanded to offshore field [2]. In the case of wind turbine, the size of generators is becoming larger due to the formation of large-scale industrial complexes, and in order to increase the power generation efficiency, the need for floating type offshore wind turbine is gradually increasing.

The design of the substructure is one of the most important issues in case of motion characteristics in the ocean rather than on the coast. Tri-pod type is attracting attention because it is easy to manufacture and efficient to reduce environmental load. However, the motion characteristics of these types of structures have not been clarified yet and are currently studied. In the case of heave plates, it affects the vertical motion of the column by forcing the viscous damping by attaching to the structure [3]. In order to improve the float performance, it is necessary to apply the optimal float design such as size, weight, water plane area, and mooring to each design. To research the effect of tri-pod type structure on the column characteristics of the float for optimum design, the influence of the column diameter and draft on the design of the substructure shape is evaluated. In this study, the semi-
The submersible model of the NREL 5MW wind turbine generator was adopted as the standard model. The displacement was fixed and the diameter changed to about ±20%.

2. Data

2.1. Standard model
The model adopted in this study is NREL 5MW wind turbine generator. The main specifications are shown in Table 1.

| Rating                  | 5MW                        |
|-------------------------|-----------------------------|
| Rotor orientation, configuration | Upwind, 3 blades            |
| Control                 | Variable speed, collective pitch |
| Drivetrain              | High speed, multiple-stage gearbox |
| Rotor, hub diameter     | 126m, 3m                    |
| Hub height              | 90m                         |
| Cut-in, rated, cut-out wind speed | 3m/s, 11.4m/s, 25m/s       |
| Cut-in, rated rotor speed | 6.9rpm, 12.1rpm             |
| Rated tip speed         | 80m/s                       |
| Overhang, shaft tilt, precone | 5m, 5°, 2.5°               |
| Rotor mass              | 110,000kg                   |
| Nacelle mass            | 240,000kg                   |
| Tower mass              | 347,500kg                   |
| Coordinate location of overall CM | (-0.2m, 0.0m, 64.0m)        |

2.2. Model Experiment

Figure 1 is a photograph of Model 1 used in this study. It was made in the form of Tri-pod semi-submersible.

Table 2 shows the main dimensions of the model made in figure 1 as dimensions, and the weight of the model was accommodated within the error range of 1%.

The purpose of this study is to evaluate the effect of the structure on the change of diameter and draft. Therefore, the displacement, thickness and size of heave plate are fixed.
Table 2. Main dimensions of model.

|          | M₁   | M₂   | M₃   | M₄   | M₅   |
|----------|------|------|------|------|------|
| Diameter | m    | 0.08 | 0.09 | 0.10 | 0.11 |
| Length   | m    | 0.396| 0.314| 0.255| 0.211|
| Column interval | m | 0.36 | 0.35 | 0.34 | 0.33 |
| Weight   | kg   | 3.180| 3.120| 3.170| 3.150|
| Displacement | kg |       |      |      | 6.024|
| Heave Plate Diameter | m | 0.16  |      |      |      |
| Heave plate thickness | m | 0.03  |      |      |      |

Table 3 shows the main materials for making the model. The structure was made of acrylic, the bracing was made of wood, and sand was used to match the draft. In order to prevent the internal structure from moving, the margins were fixed to the PE form.

Table 3. Material of the model.

| Material          | Structure | Bracing | Draft setting | Blank space |
|-------------------|-----------|---------|---------------|-------------|
| Material          | Acrylic   | Wood    | Sand          | PE Form     |

2.3. Experimental data

In the model experiment, 5 models were repeated 3 times. We tried to carry out the experiment with 3 to 20 period wave which is commonly used [4]. However, it was difficult to generate the short wave in the experimental environment. In the end, the experiment was conducted about 7 to 20 period wave.

Table 4 shows the values obtained by reducing to 1: 100 in consideration of the law of superiority [5].

For the mooring, the TLP method was used, and the spring constant $K$ used for mooring was 809 N/m.

Table 4. Experimental data.

| Period (s) | Frequency (rad/s) | Wave Height (m) | Water Depth (m) |
|------------|-------------------|-----------------|-----------------|
| 0.7        | 8.97598           |                 |                 |
| 0.8        | 7.85398           |                 |                 |
| 0.9        | 6.98132           |                 |                 |
| 1.0        | 6.28319           |                 |                 |
| 1.1        | 5.71199           |                 |                 |
| 1.2        | 5.23599           |                 |                 |
| 1.3        | 4.83322           | 0.06            | 0.95            |
| 1.4        | 4.48799           |                 |                 |
| 1.5        | 4.18879           |                 |                 |
| 1.6        | 3.92699           |                 |                 |
| 1.7        | 3.69599           |                 |                 |
| 1.8        | 3.49066           |                 |                 |
| 1.9        | 3.30694           |                 |                 |
| 2.0        | 3.14159           |                 |                 |
3. Analysis of experimental results

3.1. Six degrees of freedom analysis
In this study, we researched the 6 Degree of freedom motion of a model by generating a wave. The data were analyzed using a motive program. In the case of roll, pitch and yaw, data could not be obtained due to error values. In case of surge, sway, and heave, position data were obtained within a small error range without error value.

3.2. RAO Analysis
Figures 2 to 4 show. The RAO of Heave and Pitch, which are the most influential motions in the ocean structure about the six degrees of freedom motion. And since it is an experiment for a wave in one direction, it also shows surge RAO. Due to the error in the rotation data, the pitch RAO is represented by two models.

Figure 2. Surge RAO.

Figure 2 shows the Surge RAO of model 1 to model 5. Three repetition experiments were performed for each model, three points for each frequency are displayed in the error bar. In the case of surge RAO, there is no significant difference between the models.

Figure 3. Heave RAO.

Figure 3 shows the Heave RAO of model 1 to 5. In the Heave RAO, three repetition experiments were performed for each model, three points for each frequency are displayed in the error bar. As the number of models increases, the data size also tends to increase.
Figure 4 shows the Pitch RAO of model 1 and model 5. In the Pitch RAO, three repetition experiments were performed for each model, three points for each frequency are displayed in the error bar. As the number of models increases, the data size also tends to increase. Rotation data was analyzed only by two models due to errors. However, the data shows that it is the same trend as the Heave RAO.

4. Conclusions and Future Research

In this study, the NREL 5MW wind turbine was adopted as a standard model and reduced to 1:100 size, and the RAO of a tri-pod type semi-submersible substructure was researched. Model tests conducted on five models showed that the RAO of each model was researched by varying the diameter and draft of the column and fixing the displacement of the column. As a result, it was confirmed that the smaller the diameter of the column the more stable the motion.

Based on RAO that were confirmed as five model tests, we will simulate the floating offshore wind turbine using SW the optimum design is performed by comparing and analyzing the RAO and SW programming results of each motion obtained from the model experiment.

Review

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