Motion Performances of 5-MW Floating Offshore Wind Turbine under Combined Environmental Conditions in the East Sea, Korea

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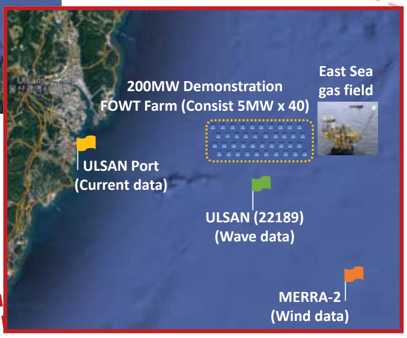
Introduction

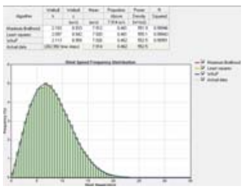
The world is interested in renewable energy more than ever, and Korea plans to increase the proportion of renewable energy to 20% by 2030 under the 3020 renewable energy policy. Among them, 16.5*GW* (34%) is planned to be covered from wind energy, and the capacity of offshore wind energy is about 13*GW*. Considering domestic technological wind resource potential (33.2*GW*), it seems to be a sufficient target amount. Offshore wind power is fixed type that is installed in shallow water depth, and there is floating type which is installed in deep sea. In order to achieve the renewable energy 3020 target, floating offshore wind turbine must be considered which can utilize abundant wind resources and extensive sea area. Therefore, in this paper, the motion analysis of a floating offshore wind turbine system using a semi-submersible and a spar platform based on the domestic marine environment conditions was performed. The domestic marine environment was designated the area near the East Sea gas field 50*km* away from the coast of Ulsan. Numerical analysis was performed using FAST v8 developed by NREL

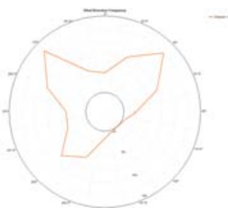
Environmental Conditions

- For the domestic environmental conditions, we used the area within 50km from the East Sea gas field.
- MERRA-2 is the reanalysis data carried out by NASA, and its coordinates are located about 38.5km from the East Sea gas field.
- Wave data based on the observation at the Meteorological Department of Ulsan buoy(22189), located about 17.3km away from the East Sea gas field.
- Current based on the observed data in Ulsan port, the observation station located about 51.73km away from the East Sea gas field.



Wind Data





Description	Value
Data name	MERRA-2
Measurement location	N35.30, E130.00
Measurement period	1998-01-01 00:00 ~ 2018-01-01 00:00
Measurement height	50 [m]
Measurement interval	1 [hr]
Mean wind speed	7.914 [m/s]
Weibull k	2.103
Power law exponent (α)	0.14

Description	Value
V_{ref} (50yr) wind speed	40.424 [m/s]
Main wind direction	45°, 225°, 315°

Wave Data

3m-Discus Data Buoy

6m-NOMAD Data Buoy

Source: http://www.weather.go.kr/HELP/html/help_sfc003.jsp

Description	Value
Data name	Ulsan (22189)
Measurement period	1998-01-01 00:00 ~ 2018-01-01 00:00
Measurement interval	1 [hr]
Significant Wave height (50yr)	11.459 [m]
Significant Wave period1 (50yr)	11.996 [s]
Significant Wave period2 (50yr)	13.726 [s]
Significant Wave period3 (50yr)	15.455 [s]

Current Data

Description		Value
Summer	Surface layer	0.7716 ~ 0.9259 [m/s]
	Bottom layer	0.2572 ~ 0.5144 [m/s]
Winter	Surface layer	0.2572 ~ 0.3086 [m/s]
	Bottom layer	0.0360 ~ 0.1698 [m/s]

Description	Value
Water depth	150 [m]
Design wave height	10 [m]
Design wave period	13 [s]
Current speed of bed	0.5144 [m/s]
Strength of bed	Middle

Design Load Cases

- Design load cases were selected by referring to IEC 61400-3.

- DLC1.2 and DLC1.6a was selected for considering the power production condition and DLC6.1a was selected for considering the parked condition.
- In DLC1.2, fatigue analysis was performed.
- In DLC1.6a, severe sea state of the East Sea gas field was applied under normal operating condition.
- In DLC6.1a, extreme environmental conditions were applied in order to consider stability in situations such as typhoons.

Description	DLC 1.2	DLC 1.6a	DLC 6.1a
Wind	NTM	NTM	EWM
Waves	NSS	SSS	ESS
Wind and wave directionality	0º, COD	0º, COD	MUL, COD
Current	NCM	NCM	ECM
Water level	150 [m]	150 [m]	150 [m]
Safety factor	No factor	1.35	1.35

5-MW wind turbine systems

Source: Definition Floating system for phase Ⅱ of OC4

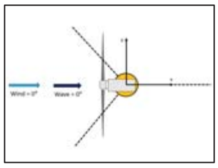
- The NREL 5-MW wind turbine was selected for the upper structure used in the numerical analysis.
- OC3-spar and OC4 semi-submersible type platforms are used for the comparison.
- Mooring system is redesigned for 150m water depth. Pretension of the redesigned mooring line was maintained, and the diameter was adjusted to maintain the angle at the fairlead. Touchdown length was redesigned, that was longer than before to prevent lift up at the anchor.

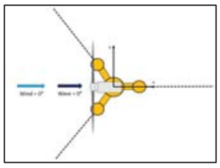
Parameters	unit	OC3-Spar	OC4-Semi
Number of Mooring Lines	-	3	3
Angle Between Adjacent Lines	º	120	120
Depth to Anchors Below SWL (Water Depth)	m	150	150
Depth to Fairleads Below SWL	m	70	14
Radius to Anchors from Platform Centerline	m	485.4	812
Radius to Fairleads from Platform Centerline	m	5.2	40.868
Unstretched Mooring Line Length	m	500	800
Mooring Line Diameter	m	0.117	0.09
Equivalent Mooring Line Mass Density	kg/m	300	178
Equivalent Mooring Line Weight in Water	N/m	2567	1519
Equivalent Mooring Line Extensional Stiffness	MN	1.30E+03	729

Source: Definition Floating system for phase Ⅳ of OC3

Results

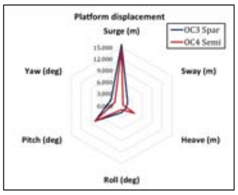
DLC 1.2 & 1.6a

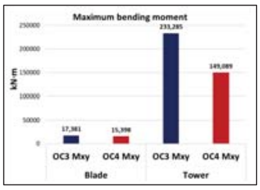


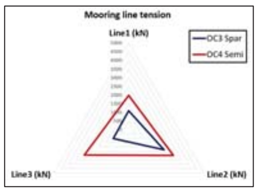


- The fatigue load calculated using MLife program. And the results compared with the land-based wind turbine.

Lifetime Damage	OC3/Land	OC4/Land
Blade root x-Bending Moment	0.97	1.06
Blade root y-Bending Moment	2.70	1.56
Tower base x-Bending Moment	2.25	1.46
Tower base y-Bending Moment	6.50	1.55

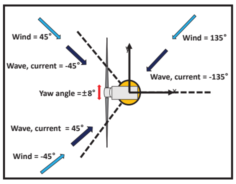


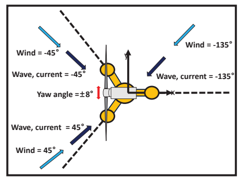


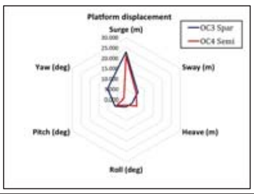


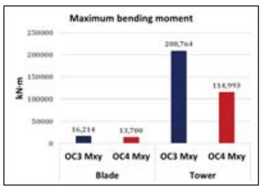
DLC 6.1a

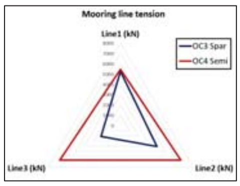
Description	OC3 Spar	OC4 Semi
Diameter	117 [mm]	90 [mm]
Chain class	Studless R3	Studless R3
Breaking load	10574.37 [kN]	6647.18 [kN]
Max tension	5261.58 [kN]	6717.35 [kN]











Conclusions

- In DLC1.6a and DLC 6.1a, the Heave motion of Semi type is about 2m larger than spar type. And, the Yaw motion of Spar type is about 5° larger. From this result, in order to use Spar type platform, additional yaw spring stiffness should be estimated appropriately when designing mooring line.
- Under extreme environmental conditions, the spar type receives a larger bending moment than semi type at blade root and the tower base part. Also, the fatigue load of spar type at tower base part is 6.5 times of the land-based wind turbine and more than 4 times of semi type. From these results, it becomes necessary to design sufficient stiffness for stress concentration part in order to use spar type platform.
- Under the extreme environment conditions, the maximum mooring line tension acting on the semi type exceeded the fracture limit. Therefore, mooring system should be redesigned after selecting the appropriate platform for allowing the floating offshore wind turbine that could operate within the mooring line fracture limit.

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