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Dynamic Responses Analysis for Initial Design of a 12 MW Floating Offshore Wind Turbine with Semi-Submersible Platform

Junbae Kim*, Pham Thanh Dam, Byoungcheon Seo, Hyunkyoung Shin†
School of Naval Architecture and Ocean Engineering, University of Ulsan, Korea

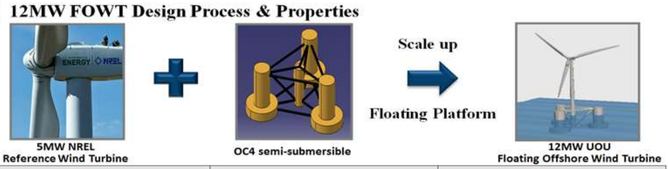
Introduction

- Why do we need 12 MW Floating Offshore Wind turbine (FOWT)?
  - Able to use in Deep Water : the stable and strong wind flows.
  - Improve energy production capacity and reduce construction costs.
  - Solution for noise and insufficient space.
- The purpose with the design of a 12 MW UOU(University of Ulsan) FOWT.
  - Desing of FOWTs must consider both aerodynamics and hydrodynamics.
  - The floating platform has the lowest natural frequencies.
  - Initial dimensional design of tower to avoid buckling and resonances.
  - Solution for unstable coupling between platform motion and pitch controller
- Dynamic responses analysis for initial design of a 12 MW UOU FOWT using fully coupled analysis was performed to determine the suitability.

Design of 12 MW Floating Offshore Wind Turbine

- The initial design of 12 MW UOU FOWT was performed based on a 5 MW NREL wind turbine for offshore model, using geometric laws of similarity.

▣ 12MW FOWT Design Process & Properties



	5 MW	12 MW
Rating	5 MW	12 MW
Control	Variable Speed, Collective Pitch	Variable Speed, Collective Pitch
Drivetrain	High Speed, Multiple-Stage Gearbox	Low Speed, Direct Drive(gearless)
Rotor, Hub Diameter	126 m, 3 m	195.2 m, 4.64 m
Hub Height	90 m	124.6 m
Cut-In, Rated, Cut-Out Wind Speed	3 m/s, 11.4 m/s, 25 m/s	3 m/s, 11.2 m/s, 25 m/s
Cut-In, Rated Rotor Speed	6.9 rpm, 12.1 rpm	3.03 rpm, 8.25 rpm
Overhang, Shaft Tilt, Pre-cone	5 m, 5°, 2.5°	7.78 m, 5°, 3°
Rotor Mass	110,000 kg	297,660 kg
Nacelle Mass	240,000 kg	400,000 kg (*Target*)
Tower Mass (for offshore)	249,718 kg	781,964 kg

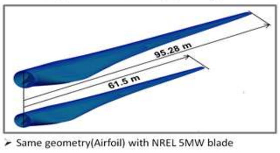
▣ Geometric Scale Ratio

- $P = C_p * \frac{1}{2}\rho A V^3$
- $\lambda_g = \sqrt{\frac{12MW}{5MW}} = \sqrt{\frac{A_{12}}{A_5}} = \sqrt{\frac{P_{12}}{P_5}} = 1.549$

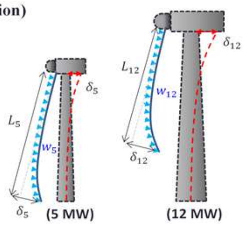
- P : Rotor power (kW)
- C_p : Max. power coefficient of rotor
- ρ : Air density. (1.225 kg/m³)
- A : Rotor swept area (m²)
- V : Wind Speed (m/s)
- λ_g : Geometric scale ratio

▣ Scale-up Blade & Tower properties (Beam deflection)

- 61.5 (m) 5MW glass blade : 17.7 ton
- 95.28 (m) 12MW carbon (spar cap) blade : 42.7 ton



➤ Same geometry(Airfoil) with NREL 5MW blade



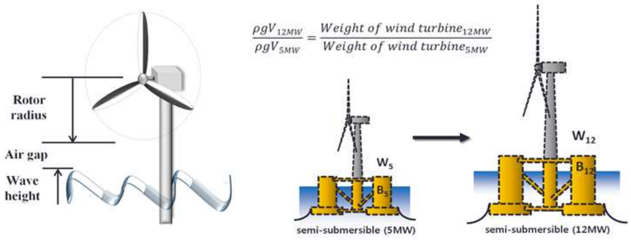
▣ Hub height

- Rotor radius + Extreme wave height (half) with 50-year occurrence × S.F. of 1.8
  : 97.6 + 30.0 / 2 × 1.8 = 124.6 m

▣ Scale-up Platform properties

- Ratio of W_{12}(1480ton) to W_5(600ton)
- OC4 semi-submersible "displaced volume" 13,917m³ (5MW) → 34,336m³ (12MW)

$$\frac{\rho g V_{12MW}}{\rho g V_{5MW}} = \frac{Weight\ of\ wind\ turbine_{12MW}}{Weight\ of\ wind\ turbine_{5MW}}$$



Tower Buckling Analysis

▣ Critical load (P_{cr}) from Euler equation

- $P_{cr} = \frac{\pi^2 EI}{l_e^2} = \frac{\pi^2 EI}{(Kl)^2}$
- $\sigma_{cr} = \frac{P_{cr}}{A}$

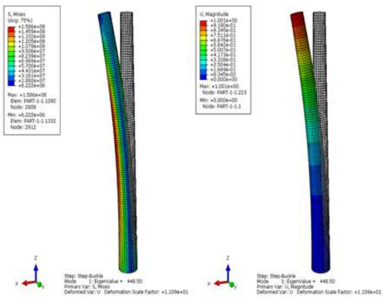
▣ Effective load (P_{eff}) of tower axial weight

- $P_{eff} = \frac{33}{140} * W_{Tower} + W_{Head}$
- Equivalent weight of tower
- W_{Head} : Lumped mass of Rotor & Nacelle

▣ Analysis Results (ABAQUS)

σ_{cr} (N)	P_{cr} (N)	P_{eff} (N)	δ (m)
1.586.E+08	7.963.E+07	8.649.E+06	1.001

➤ $P_{cr} < P_{eff}$: the tower is stable



Tower Resonance Analysis

- A tower design is proposed to avoid the 3P resonance problem due to the direct expansion of the 5 MW wind turbine support.

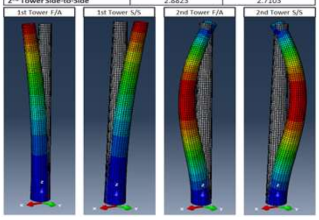
▣ Tower Redesign

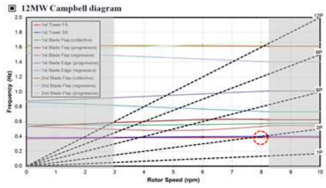
- Frequency is inversely proportional to length → Reduced the tower length

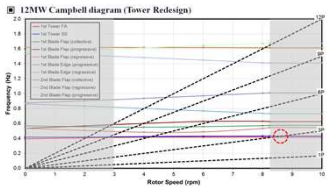
	Tower length	Tower-base diameter	Tower-base thickness	Tower-top diameter	Tower-top thickness	Tower weight
Before	110.88 m	9.634 m	0.040 m	5.736 m	0.028 m	781,964 kg
After	104.23 m	9.634 m	0.040 m	5.736 m	0.028 m	735,066 kg

▣ 12 MW Tower Natural Frequencies (ABAQUS)

Mode	FAST (MBC3)	ABAQUS
1st Tower Fore-Aft	0.3195	0.3310
1st Tower Side-to-Side	0.3327	0.3310
2nd Tower Fore-Aft	2.7888	2.6997
2nd Tower Side-to-Side	2.8823	2.7103



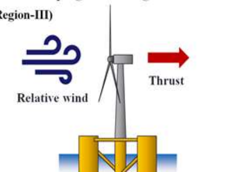




Control system of 12MW FOWT

- In the case of a FOWT, the negative damping problem occurs when applying conventional pitch control system of land-base wind turbine.
- The negative damping has the reducing rated power and increasing fatigue load.
- 12 MW FOWT was modified, the PI controller to avoid negative damping problem and the response speed of the blade pitch controller to be lower than the response speed of the platform.

▣ Negative damping of Floating Offshore Wind Turbine (In Region-III)



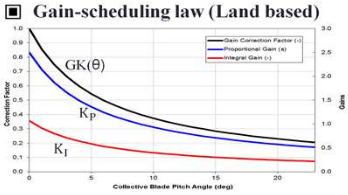
- Tilt out of wind
  - Relative wind speed decrease → Thrust increase
- Tilt into wind
  - Relative wind speed increase → Thrust decrease

▣ Change the gains of PI controller, K_P and K_I

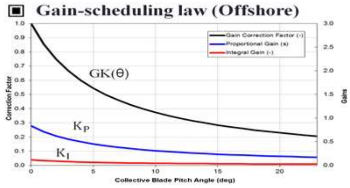
: Adjusting the response speed of the blade pitch controller to be lower than the response speed of the platform

- Natural Frequency of Platform pitch : 0.21 rad/s
- Natural Frequency of PI Contoller : 0.6 rad/s → 0.2 rad/s

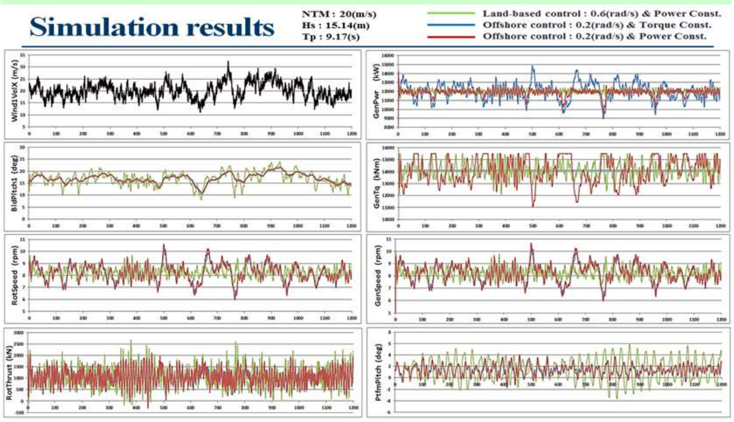
▣ Gain-scheduling law (Land based)



▣ Gain-scheduling law (Offshore)



Numerical simulation



Conclusion

- Initial design of a 12 MW UOU FOWT using fully coupled analysis was performed to determine the suitability.
- Dimensions of tower was approved by buckling analysis.
- 3P Resonance avoided through the redesign of the tower.
- Negative damping was solved through the response speed control of the blade-pitch controller.

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울산대학교 UNIVERSITY OF ULSAN

E-mail
* Author : uou99@mail.ulsan.ac.kr
† Corresponding author : hkshin@ulsan.ac.kr

산업통상자원부 MINISTRY OF TRADE, INDUSTRY & ENERGY MOTIE

KETEP 한국에너지기술평가원 KOREA INSTITUTE OF ENERGY TECHNOLOGY EVALUATION AND PLANNING