Structural Dynamic Analysis of Semi-submersible Floating Vertical Axis Wind Turbines

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Objectives

♦ The purpose of this study is to investigate the distribution of bending moment (BM) along the blade and the effect of turbulent wind on the responses of flexible components.

♦ The bending moments at critical points are to be analyze.

♦ The analysis of Short-Term Fatigue Damage Equivalent loads (STFDELS) is to be performed.
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The FVAWT concepts – FVAWTs configuration and advantages

- Rotor with geometric simplicity
- No pitch, no yaw control mechanism
- Low center of gravity
- Lower installation and maintenance cost
- Light weight rotor from DeepWind project
- Shaft connection
- Generator position
- Semi-submersible from DeepCwind OC4 project
- Mooring system

5MW Baseline FVAWT 5MW Optimised FVAWT
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Numerical Method – 5MW Optimised FVAWT’s Platform Modification

- Ballast water
- Increased ballast water

\[ F_B - F_G = W \]
Numerical Method – Simulation tool

- A fully coupled simulation tool: Simo-Riflex-DMS code
- Each blade is modelled by 75 elements. The dynamic equilibrium equations are solved at each 0.0025s time step over 4600s.

Computation and analysis flow chart for the coupled model
Numerical Method – Environmental condition

- To depict a realistic offshore condition, a combination of wind-wave environmental state is considered.

- The long-crested irregular waves in the developing sea state were generated using the JONSWAP (Joint North Sea Wave Project) spectrum with a peakedness parameter of 3.3.

Combined wind and wave environment for normal operating condition

<table>
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<th>DLC</th>
<th>$U_w$ (m/s)</th>
<th>$H_S$ (m)</th>
<th>$T_P$ (s)</th>
<th>Turbulence Model</th>
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Results – Effect of turbulent wind on power production

- 5MW Baseline FVAWT
- 5MW Optimised FVAWT
Results – Effect of turbulent wind on the bending moment distribution along the blade

- 5MW Baseline FVAWT
- 5MW Optimised FVAWT
Results – Effect of turbulent wind on tower base bending moment

- 5MW Baseline FVAWT

- 5MW Optimised FVAWT
Results – Effect of turbulent wind on the blade first node

- 5MW Baseline FVAWT

- 5MW Optimised FVAWT
Results – Effect of turbulent wind on mooring lines tension

- 5MW Baseline FVAWT

- 5MW Optimised FVAWT
Results – Effect of turbulent wind on Short Term Fatigue Damage Equivalent Loads (STFDELS)

- 5MW Baseline FVAWT
- 5MW Optimised FVAWT

STFDELS due to BMs at the blade first node

STFDELS due to the tension in mooring line 2
Results – Comparative study between both FVAWTs

- Power Production

- Blade Bending Distribution

- Platform Pitch Motion

- STFDELS of due to the tension in mooring line 2
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Conclusions

• This work focuses on the structural dynamic analysis of FVAWTs with major contribution on the distribution of bending loads along the blade and fatigue damage on flexible components which has not been fully studied for the rotor blade in the literatures.

• Two FVAWT concepts are evaluated under the same environmental conditions. The stochastic responses of both FVAWTs are studied under steady wind and turbulent wind conditions based on the statistical analysis to explore the effects of turbulence.

• The results show that the effect of turbulence on both FVAWTs results in:
  ✓ An increased power generation
  ✓ Higher power variation
  ✓ Higher excitation for low frequency motions
  ✓ Greater fatigue damage
  ✓ A reduction in the 2P effects
  ✓ Higher bending at especially at wind speed above 22m/s
  ✓ Higher mooring lines tension at wind speeds above the rated wind speed
Conclusions

• However, the effect of turbulence is negligible on the mean bending moment at the blade extremes.

• Furthermore, the results of the fatigue analysis show that at wind speeds farther from the rated wind speed (14 m/s), the bending moments could have lower damaging effects than at wind speeds closer to the rated wind speed for the 5 MW Optimised FVAWT.

• Finally, a comparison the responses between both FVAWTs shows that the 5 MW Optimised FVAWT experienced:
  
  ✓ Lower Fore-Aft (FA) bending moments at most of the critical points
  ✓ Higher variation in bending moments
  ✓ Lower motions amplitude
  ✓ Lower short-term fatigue damage equivalent loads
  ✓ A further reduced 2P effects under the turbulent wind condition
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Recommendations

• Improvement on the generator control system for the 5MW Optimised FVAWT is recommended.

• To investigate the effect of wave-wind misaligned condition for the 5MW Optimised FVAWT.

• Investigate the effect of current on the mooring line dynamics and platform global motions for the 5MW Optimised FVAWT.
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Status of the Project

• The team is currently working to improve the generator control system for the 5MW Optimised FVAWT with stabilizing power production.

• It is our assumption that the improved control strategy would significantly minimize the aerodynamic loads on the rotor.
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Main Recommended References


- Wang, K. Modelling and dynamic analysis of a semi-submersible floating vertical axis wind turbine. Faculty of Engineering Science and Technology: Department of Marine Technology; Norwegian University of Science and Technology, Norway, 2015.
Thank you