Modelling the Loads and Motions of a Floating Offshore Wind Turbine with Asymmetric Moorings

Wayne Formosa **Tonio Sant**

Department of Mechanical Engineering

L-Università ta' Malta

EERA DeepWind 2022 - Digital conference, 19 – 21 Jan, 2022

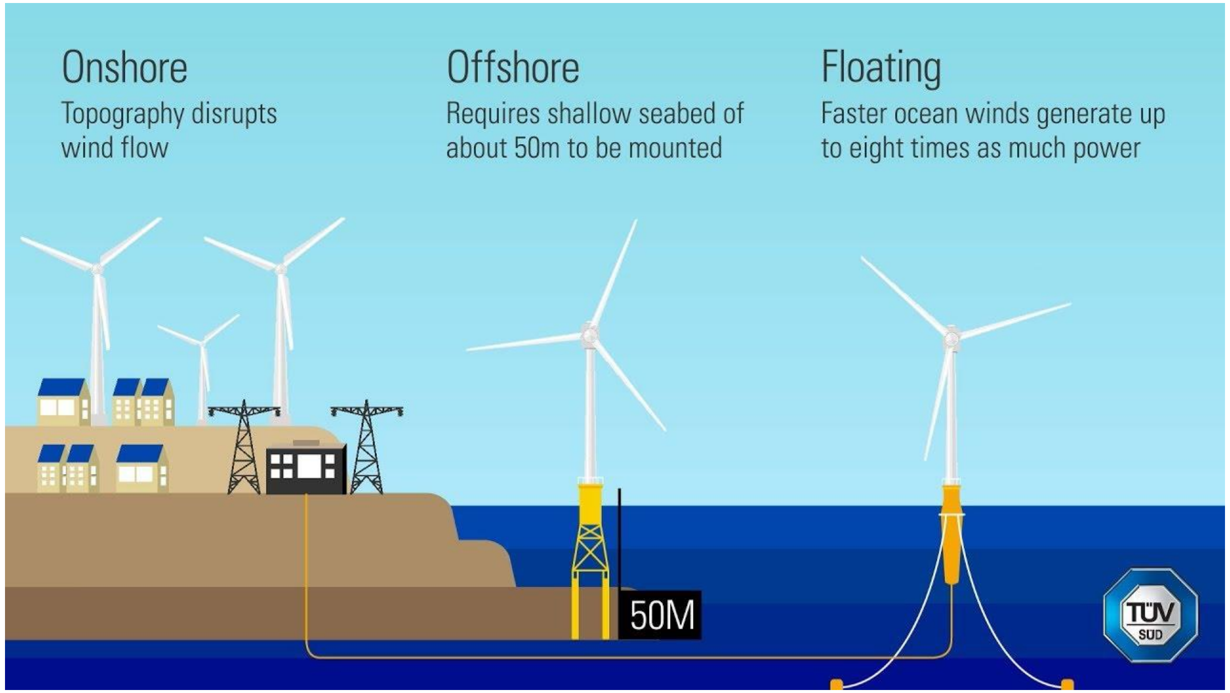
Background – Floating Offshore Wind

Advantages

- An advancing technology
- Floating support platforms enable:
  - Application of wind turbines at deep-water locations characterised by higher wind speeds
  - Minimal interaction with seabed and its inhabitants
  - Easier and cheaper installation
- A promising solution to the high energy demand

Challenge

- Turbine aerodynamic interference experienced in a wind farm results in wake losses that can reach 20% (Neiva et al., 2019)



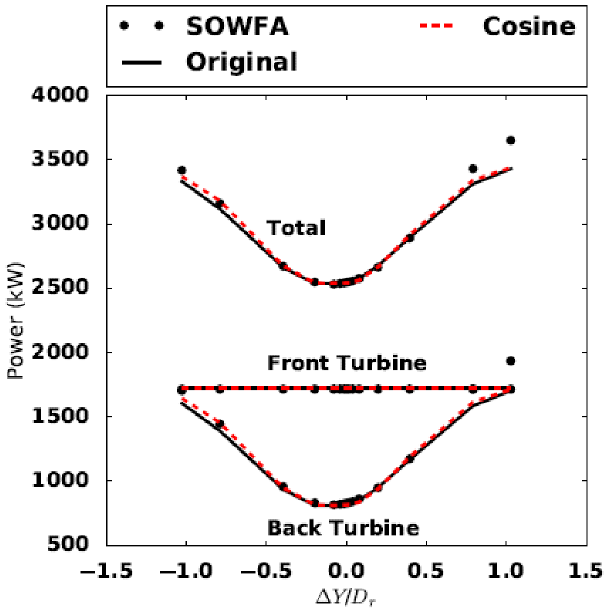
From: https://www.tuvsud.com/en-id/resource-centre/stories/floating-windfarms

Using Dynamic Positioning of Floating Turbines to reduce Wake Losses

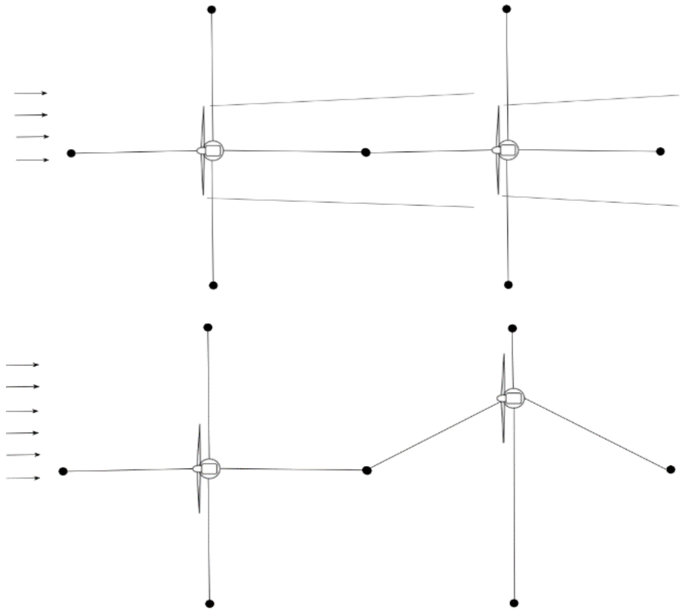
- A small crosswind displacement (~1 D) yields a significant reduction in wake losses (Thomas et al., 2017)
- Dynamic positioning can be achieved by varying the mooring lengths of floating turbines
- Wake losses are more critical for wind speeds below the rated wind speed

=> Wave heights not large for $V < V_{rated}$, hence lower risk of instability

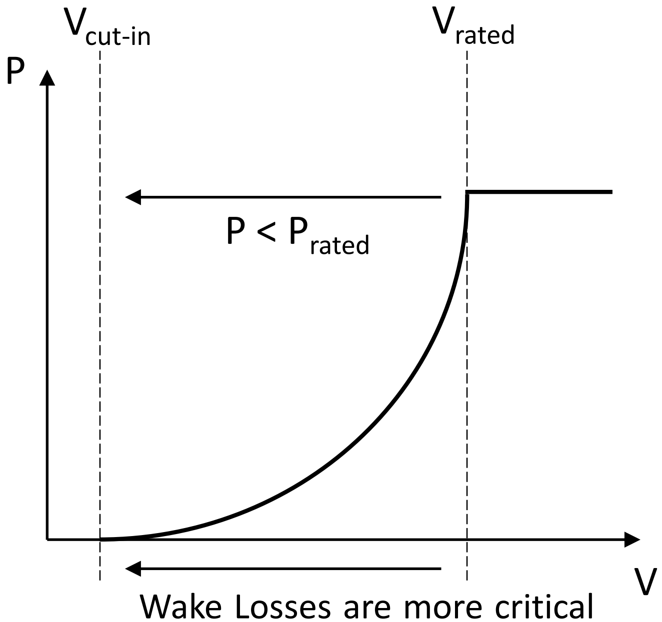
=> Dynamic positioning introduces asymmetric moorings



Thomas et al. (2017)



Dynamic Positioning



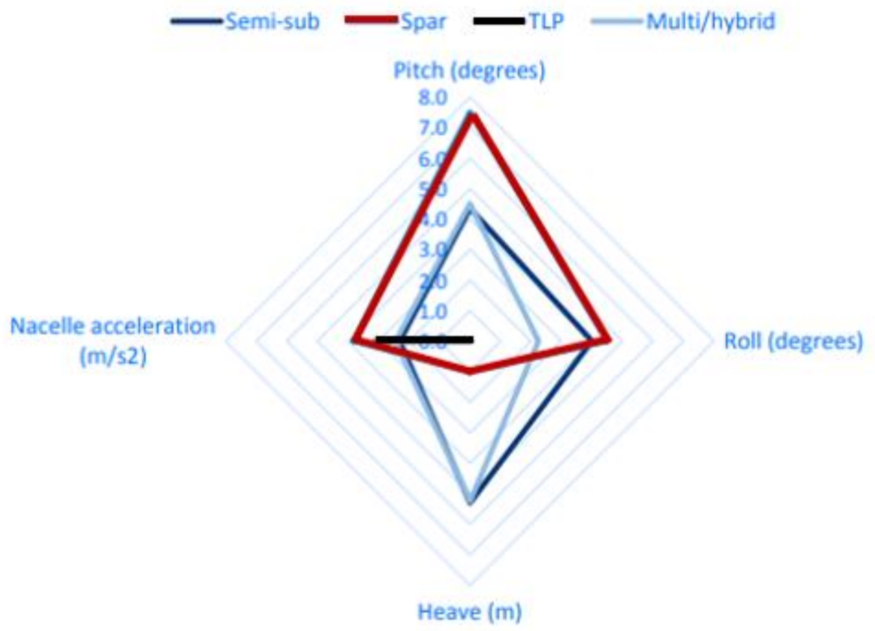
Wake Losses are more critical for $V < V_{rated}$, at which wave conditions are not extreme

Research Objective

- Using numerical modelling to investigate the influence of asymmetric moorings on the dynamic response and mooring loads of a floating offshore wind turbine under the combined influence of wind and waves

Approach

- Hydrodynamic Modelling in AQWA^{TM}
  - Model Parameters
  - Mooring Configurations
  - Test Conditions
- Hydrodynamic Response
  - Kinematics of the rotor nacelle assembly
  - Mooring Loads
  - Statistical analysis and comparison with limits
- Conclusions



Maximum Permissible Motions for FOWTs (James and Costa Ros, 2015)

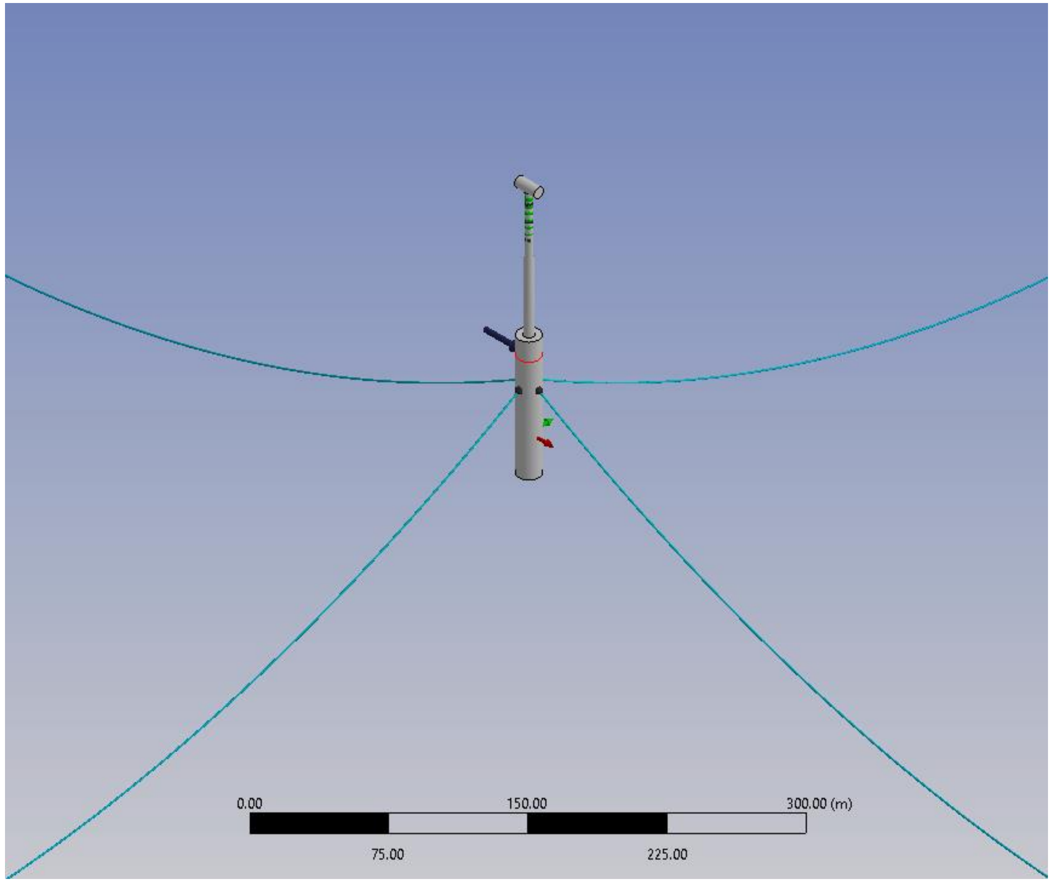
Hydrodynamic Modelling – Fixed Parameters

Turbine Characteristics

- Rated power: 6 MW
- Rated wind speed: 11.65 m/s
- Rotor diameter: 138 m
- Floating structure: spar
- Rotor not modelled in AQWA™

Mooring Characteristics

- Four moorings
- Type: Catenary (following the DNV-OS-E301 and DNV-OS-E302 standards)
- Depth from MSL to fairleads: 20 m
- Sea depth: 150 m
- Radius to anchors from neutral position: 1,153 m
- Proof load: 4,620 kN



Floating Turbine as modelled in ANSYS® AQWA™

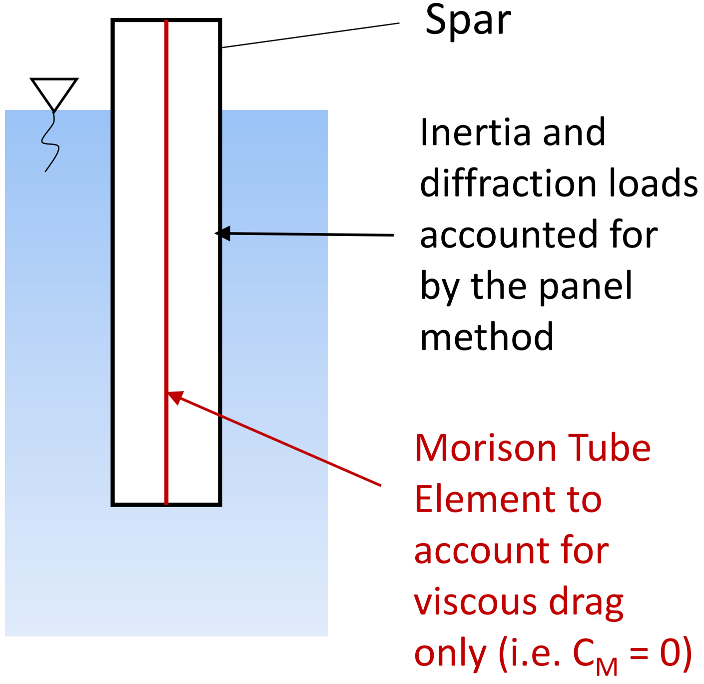
Hydrodynamic Modelling – Further Considerations

Mesh Parameters

- Defeaturing tolerance of 1 m
- Maximum element size of 2 m

Morison Tube Element

- To simulate realistic viscous effects
- Inertia force is already accounted for by the Panel method in AQWA™
- C_D for a single sided disc: 1.14 (AQWA™ Theory Manual)
- Important to maintain the same structure mass
  => Tube diameter, thickness and density divided by 100
  => C_D multiplied by 100



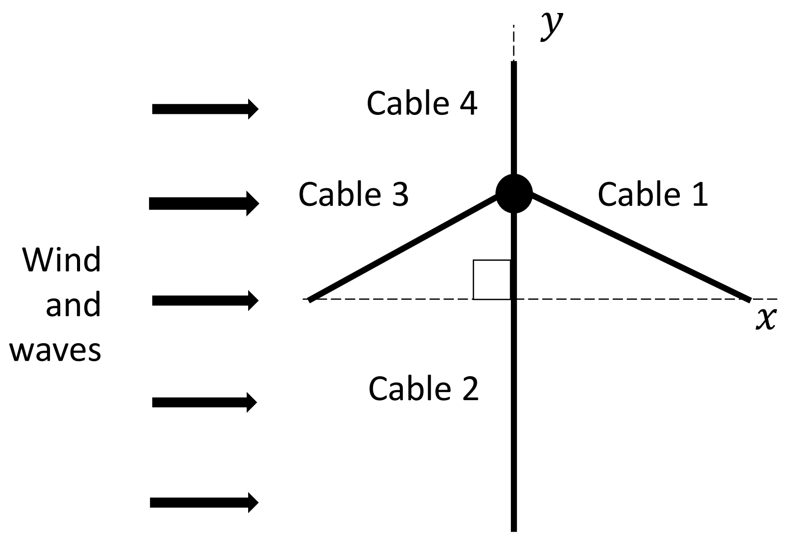
Cross-sectional view of the spar showing the Morison Tube Element

Morison Equation:

$$F_M(t) = \underbrace{\frac{1}{2}\rho_{sw} D_{so} C_D (u_f - u_s)|u_f - u_s|}_{\text{Drag Force}} + \underbrace{\rho_{sw} A' C_M \dot{u}_f - \rho_{sw} A' (C_M - 1)\dot{u}_s}_{\text{Inertia Force}}$$

Hydrodynamic Modelling – Mooring Configurations

3 levels of shift in the crosswind direction



Asymmetric Mooring Configuration for the Hydrodynamic Model

Prescribed Cable Length Variations

Degree of Shift	Length of Cable 2 (m)	Length of Cable 4 (m)	Sway Displacement (m) [in terms of rotor diameter] *
Minimum	1202	1128	36 [0.3D]
Medium	1238	1092	73 [0.5D]
Maximum	1275	1055	109 [0.8D]
Unstretched Cable Length:	**1,165 m**		

* The average sway displacement of the rotor nacelle assembly deduced from the simulations

Hydrodynamic Modelling – Test Conditions

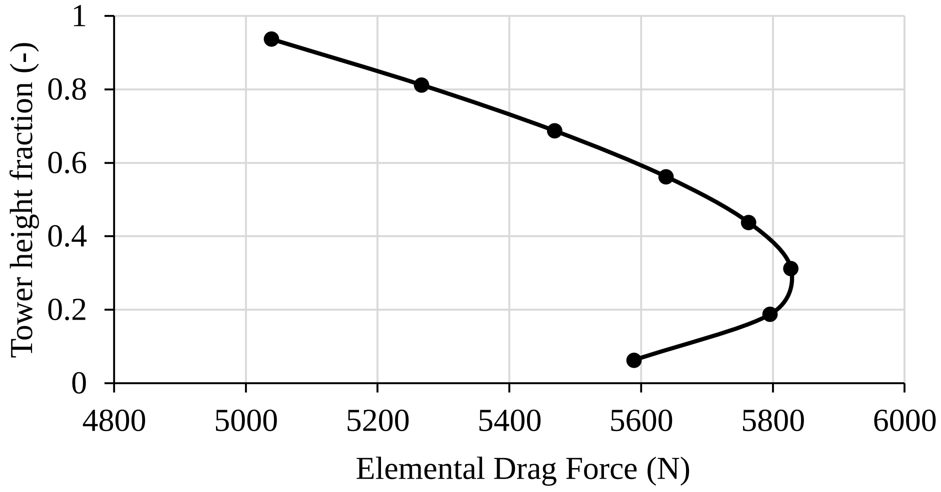
4 Load Cases representing non-extreme water conditions

Thrust Force: $T_w = \frac{1}{2} C_T \rho_a A_R U_\infty{}^2$

Logarithmic Profile: $\frac{U_\infty(z_g)}{U_\infty(z_{ref})} = \frac{\ln\left(\frac{z_g}{z_0}\right)}{\ln\left(\frac{z_{ref}}{z_0}\right)}$

Test Conditions applied to Hydrodynamic Model

Load Case	Height (m)	Period (s)	Wave Type	Model
LC 1	1.4	6.5	Regular	Airy Wave Theory
LC 2	3.66	9.7		
LC 3	1.4	6.5	Irregular	JONSWAP Wave Spectrum
LC 4	3.66	9.7		
Thrust on Rotor:		**920 kN**		
Drag on Freeboard:		**11.8 kN**		



4 LCs x 4 Turbine Positions = 16 Simulations

Simulation Time: 2400 s

Hydrodynamic Modelling – Test Conditions

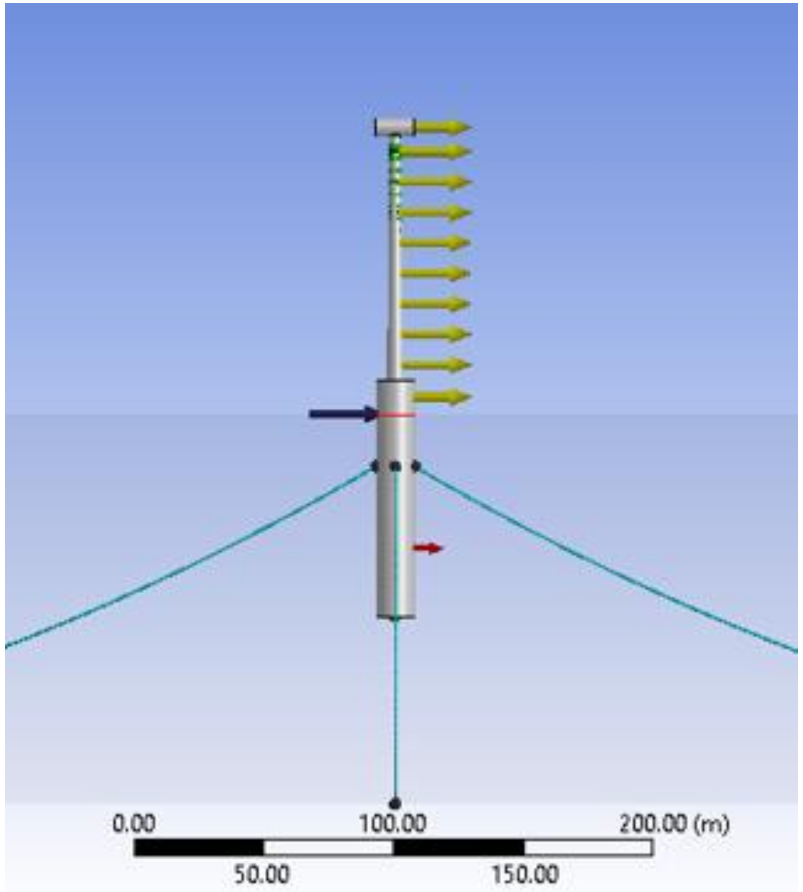
4 Load Cases representing non-extreme water conditions

Test Conditions applied to Hydrodynamic Model

Load Case	Height (m)	Period (s)	Wave Type	Model
LC 1	1.4	6.5	Regular	Airy Wave Theory
LC 2	3.66	9.7		
LC 3	1.4	6.5	Irregular	JONSWAP Wave Spectrum
LC 4	3.66	9.7		
Thrust on Rotor:		**920 kN**		
Drag on Freeboard:		**11.8 kN**		

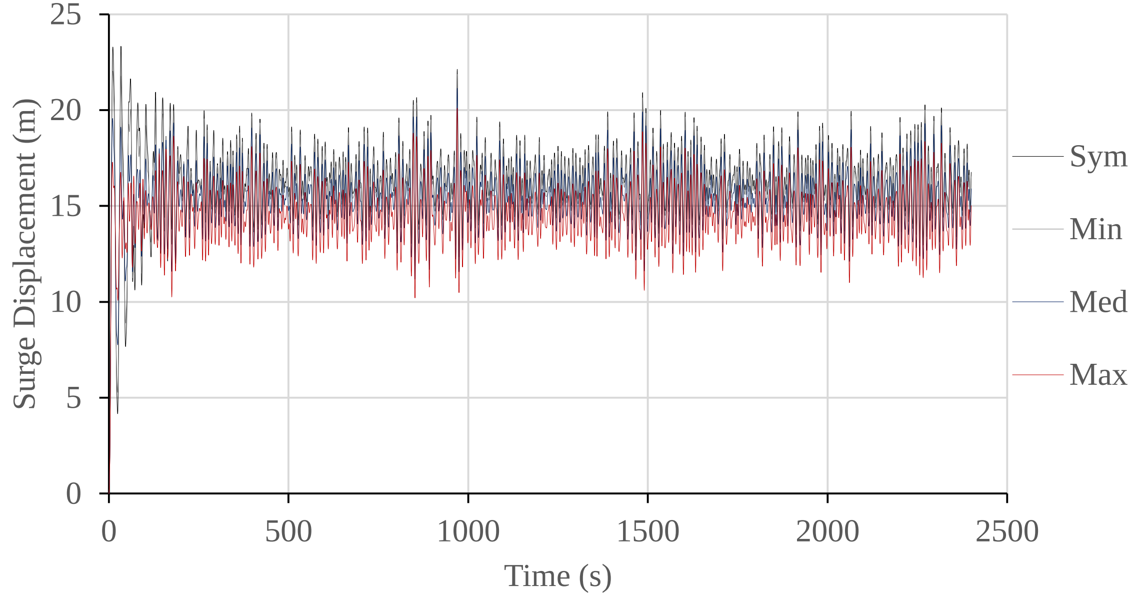
4 LCs x 4 Turbine Positions = 16 Simulations

Simulation Time: 2400 s

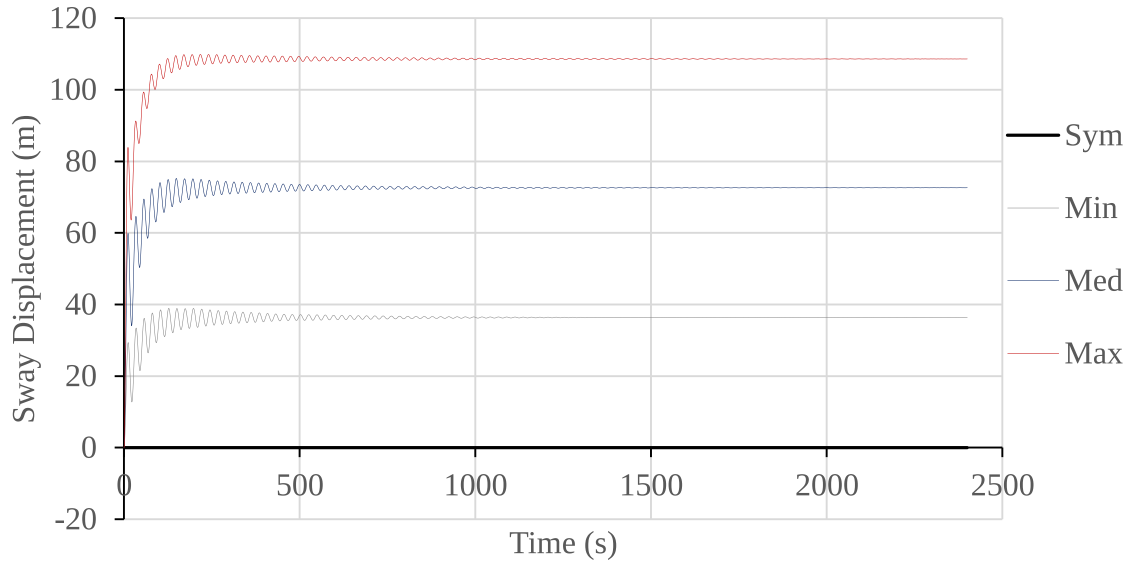


Forces Acting on Turbine in ANSYS® AQWA™

Results – Hydrodynamic Response



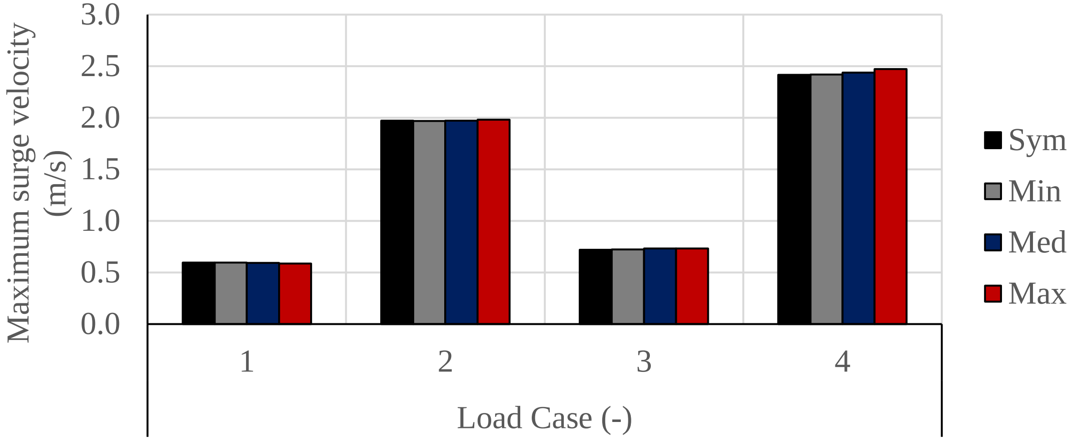
Actual Response RNA Surge Displacement for LC 4



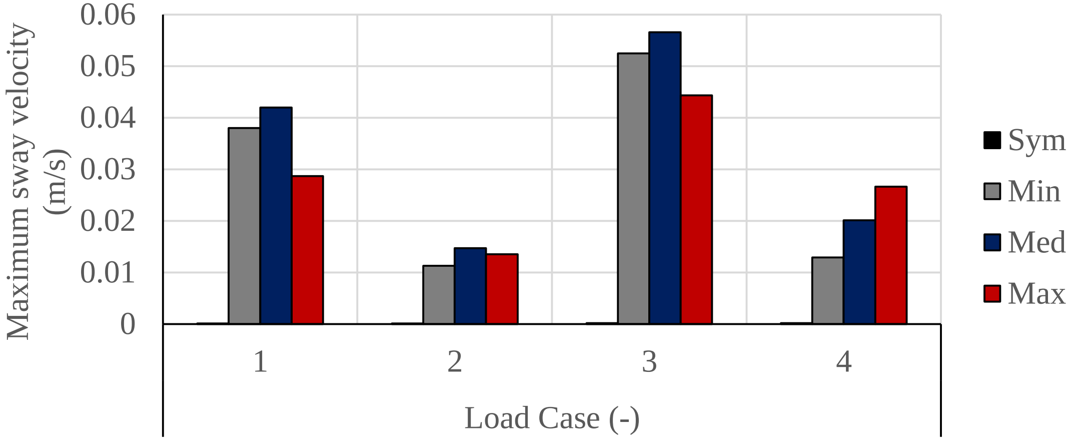
Actual Response RNA Sway Displacement for LC 4

- Statistical analysis for the last 900 s of the simulations to omit transient effects
- Comparison of results with permissible limits

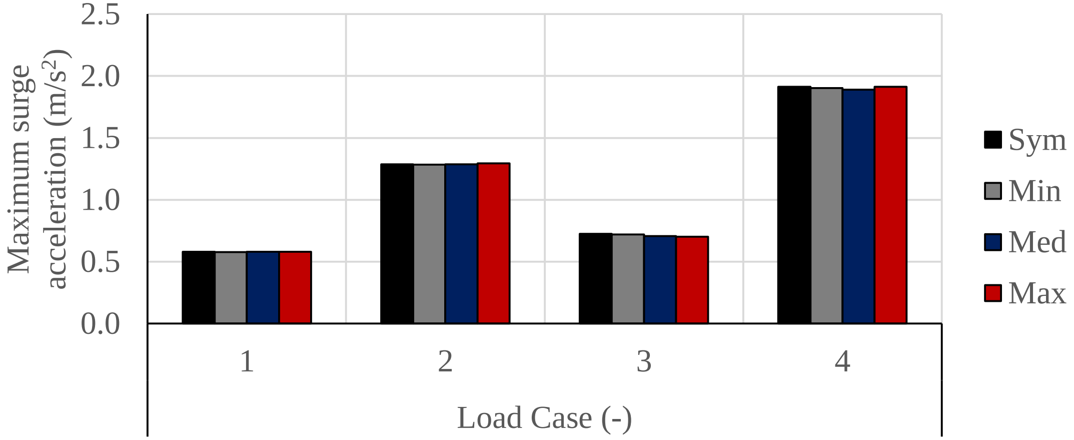
Results – Hydrodynamic Response



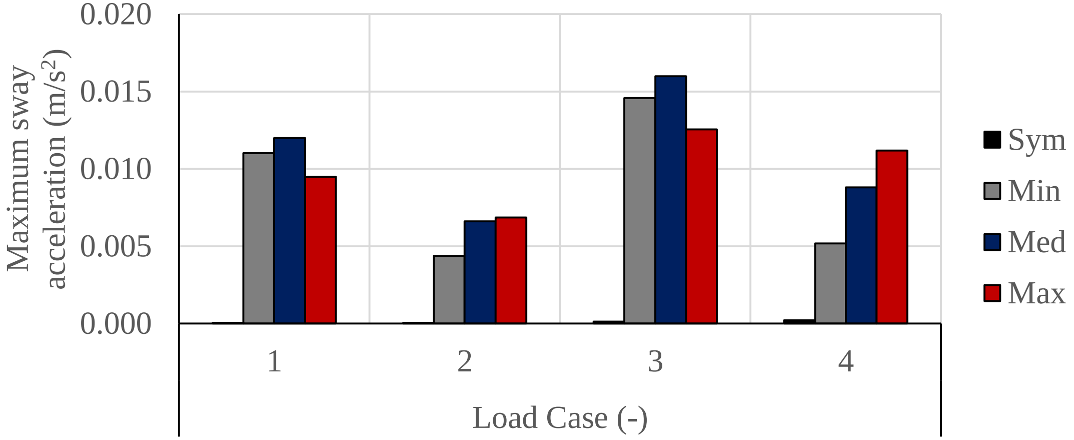
Maximum RNA Surge Velocity



Maximum RNA Sway Velocity

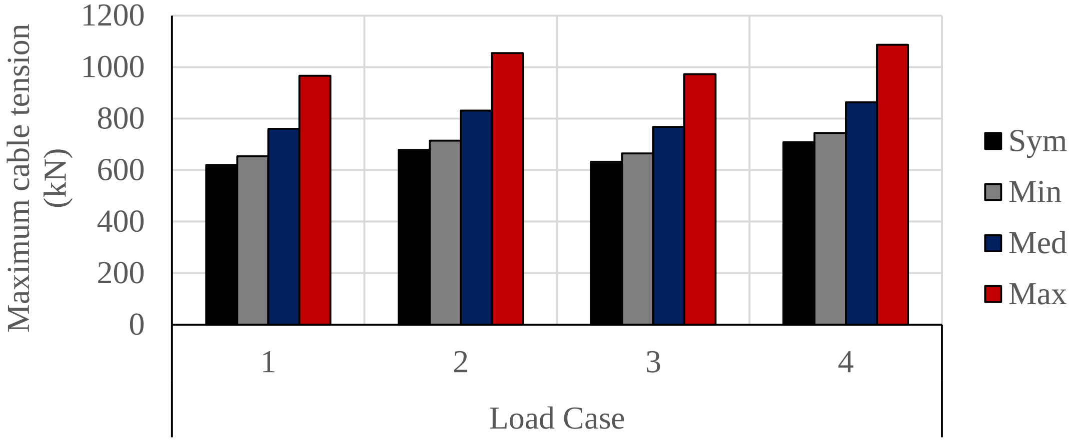


Maximum RNA Surge Acceleration

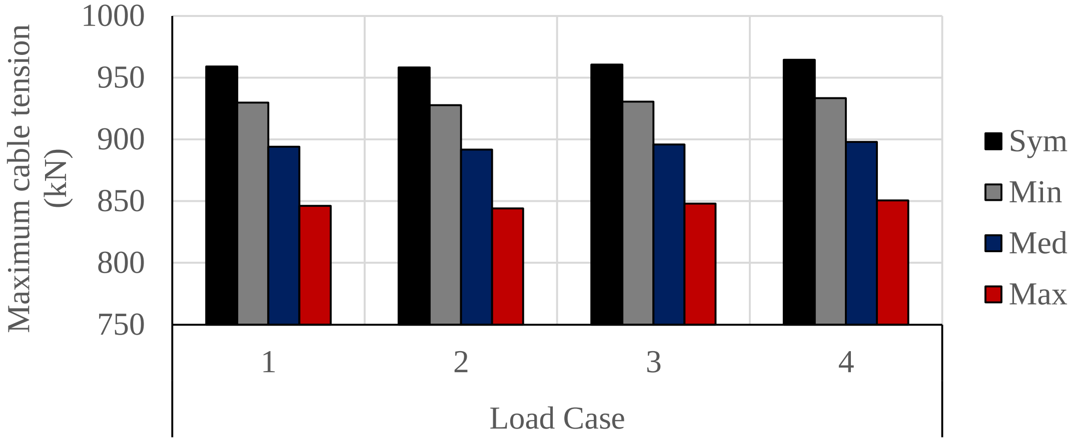


Maximum RNA Sway Acceleration

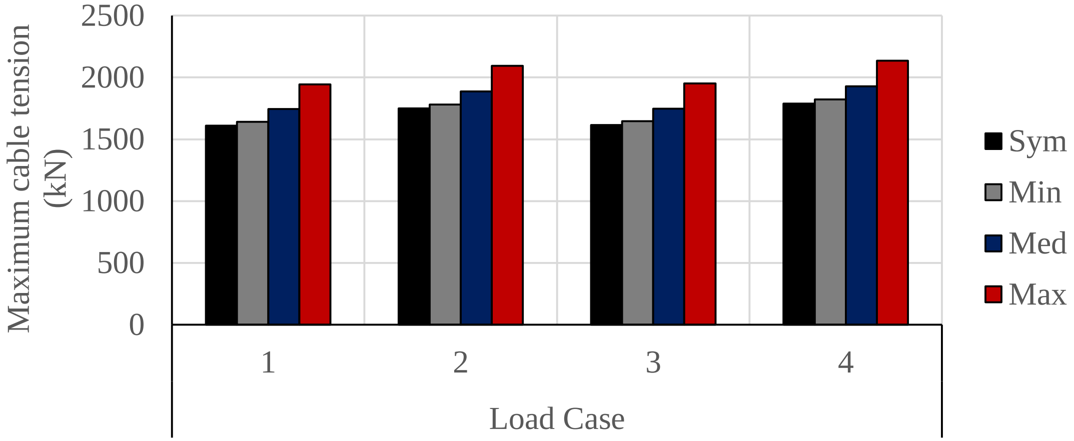
Results – Hydrodynamic Response



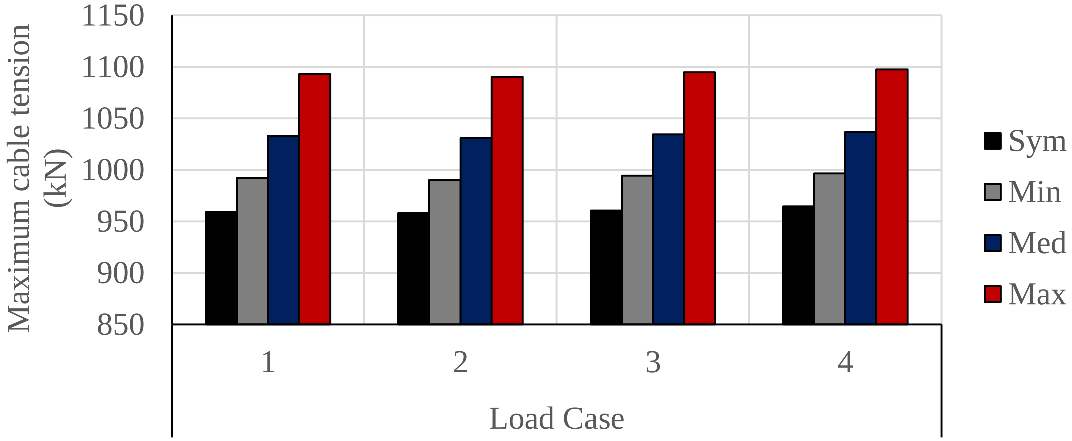
Maximum Tension in Cable 1



Maximum Tension in Cable 2



Maximum Tension in Cable 3



Maximum Tension in Cable 4

Conclusions

- The effect of asymmetry is marginal for the surge, heave and pitch motions, but significant on the sway and roll motions as well as the cable tensions. Yet the resulting increase in sway motion is still small as compared to platform surge.

- The asymmetric moorings increase the maximum nacelle accelerations, depending on wave state. Yet the increase is still within acceptable limits.

- The proof load of the moorings is not exceeded.

- An asymmetric mooring system for wind speeds equal to and below 11.65 m/s, wave heights up to 3.66 m and maximum shift of 0.8D is not expected to jeopardise the dynamic stability of a floating wind turbine.

- Applying the medium degree of shift of 0.5 D to two aligned turbines in opposite directions along the sway axis will significantly reduce the wake losses without affecting the stability of the floating wind turbines.

Thank you for your attention!