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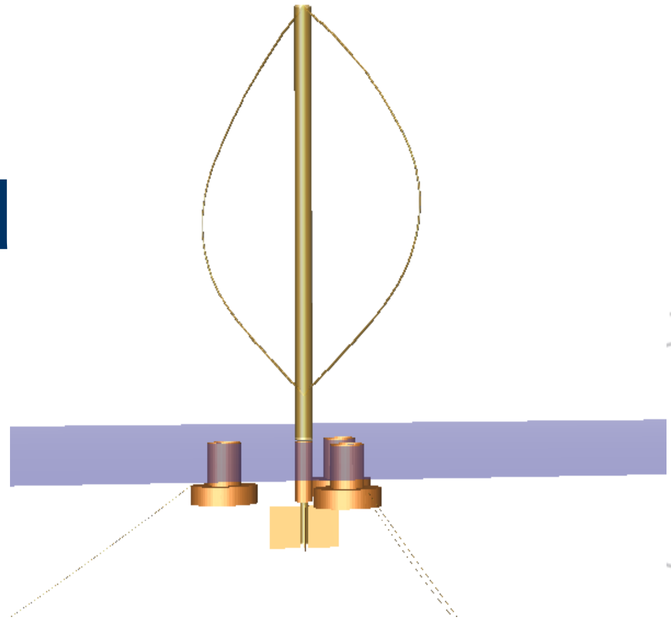
Dynamic analysis of a floating vertical axis wind turbine under emergency shutdown using hydrodynamic brake



Kai Wang, Martin O.L. Hansen and Torgeir Moan

WP6 of NOWITECH
Centre for Ships and Ocean Structures (CeSOS)
The Norwegian University of Science and Technology (NTNU)

EERA DeepWind' 2014 ,Trondheim, January 22, 2014

Outline

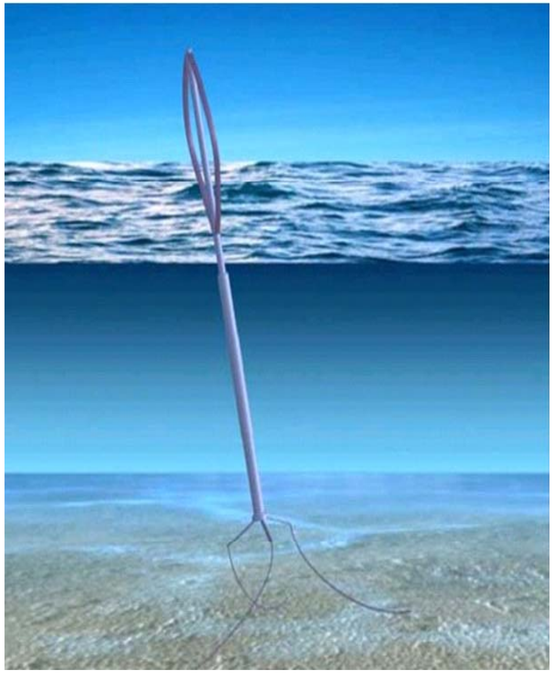
- Background and objective
- Modeling and simulation tool
- Torque estimation of the hydrodynamic brake
- Analysis results of emergency shutdown by using the hydrodynamic brake
- Concluding remarks
- Future work

Background

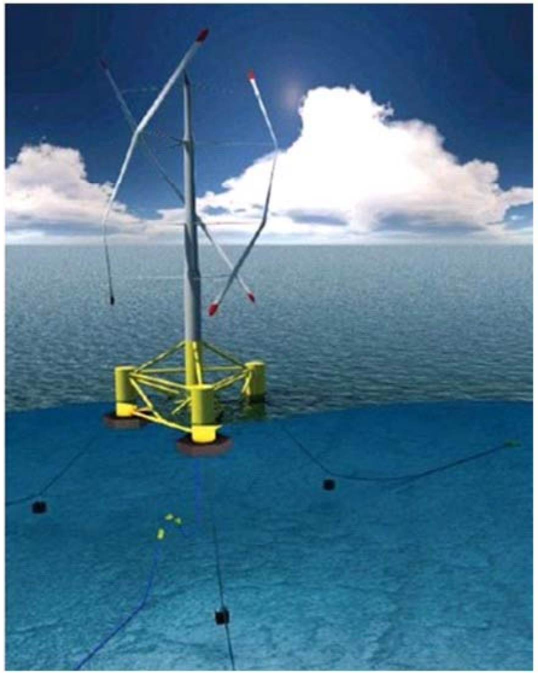
► Increasing interest in floating vertical axis wind turbines

- DeepWind Concept
- VertiWind Concept
- Aerogenerator X Concept

Vertical floating concepts



Courtesy of DeepWind Project



Courtesy of Marc Cahay

Courtesy of Wind Power Limited & Grimshaw

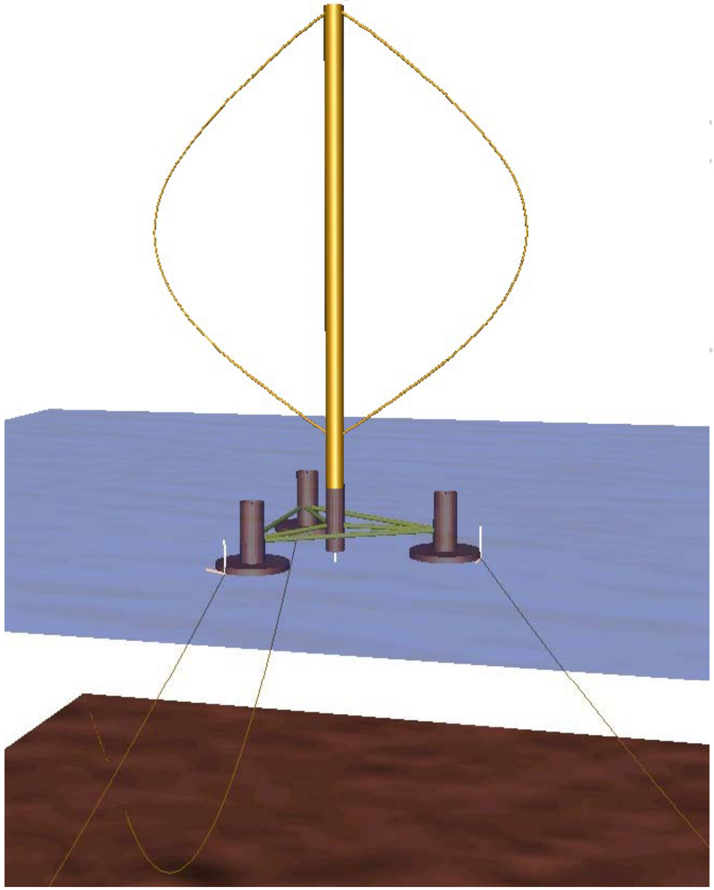
- DeepWind Concept
  - 5 MW, European project - FP7
  - Rotor Height 129.56 m
  - Rotor Radius 63.77 m
- VertiWind Concept
  - 2 MW in France
  - Rotor Height 105 m
- Aerogenerator X Concept
  - 10 MW in UK
  - Maximum Height 130 m

Background

► Increasing interest in floating vertical axis wind turbines

- DeepWind Concept
- VertiWind Concept
- Aerogenerator X Concept
- Novel concept proposed in OMAE 2013

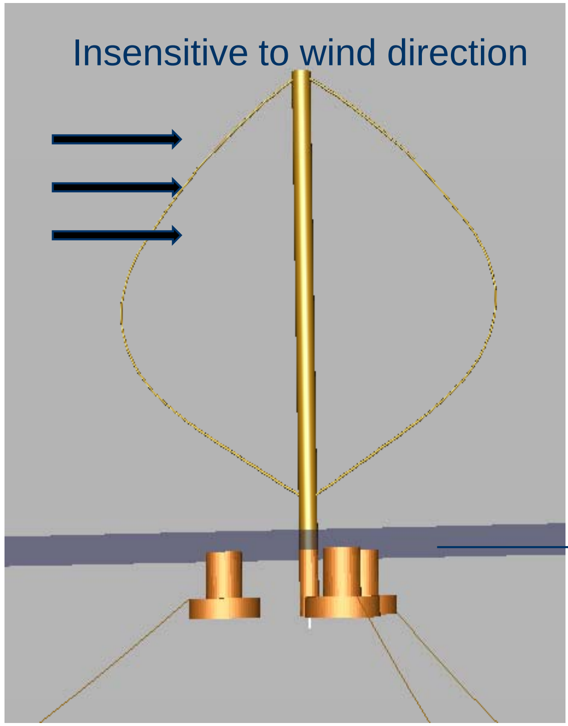
A novel concept:
- 5-MW VAWT
- Darrieus rotor
- Semi-submersible floater
- Mooring lines



Wang, K., Moan, T., and Hansen, M.O.L. A method for modeling of floating vertical axis wind turbine. in Proceedings of the 32th International Conference on Ocean, Offshore and Arctic Engineering. 2013. Nantes, France: paper no: OMAE2013-10289.

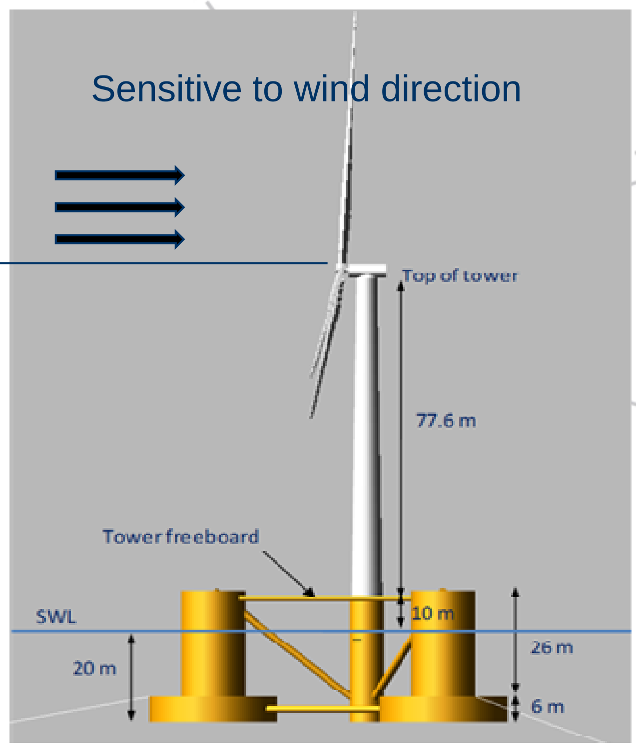
Background

- ► Increasing interest in floating vertical axis wind turbines
- ► Distinctive features of FVAWT compared with FHAWT



HAWT Components
1. Blade Pitch system
2. Yaw system
3. Gear box
4. Generator

VAWT Components
1. Gear box
2. Generator



Easy access to drivetrain
Reduce O&M costs

Difficult access to drivetrain
Increase O&M cost

Background

- ► Increasing interest in floating vertical axis wind turbines
- ► Distinctive features of FVAWTs compared with FHAWTs
- ► Drawbacks of the FVAWTs
  - ❖ Aerodynamic torque ripple resulting in cyclic loading on drive train and structures
  - ❖ Emergency shutdown situation

    Scenario: grid loss, loss of generator torque,

    failure of mechanical brake (possible happen in cold weather), stormy weather

    Measure: aerobrake (Spoilers)

Background

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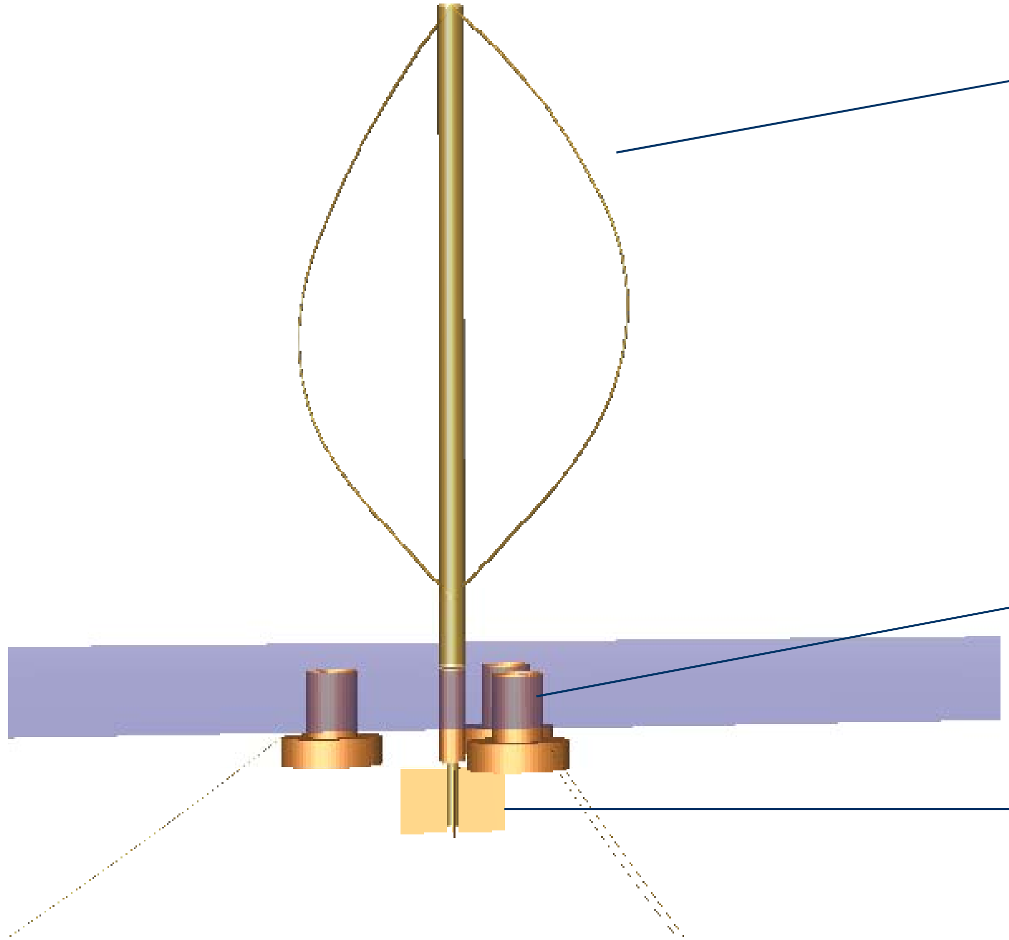
    Measure: aerobrake (Spoilers)
- ► An economic and efficient braking system is preferred

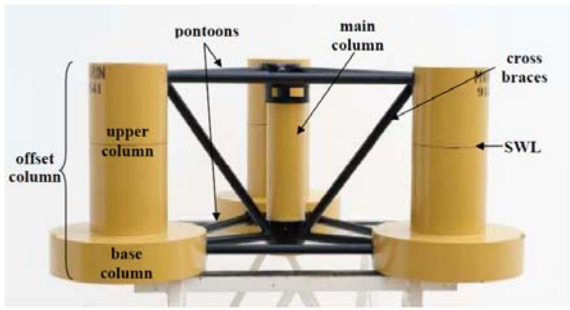
Objectives

- ► Propose a novel hydrodynamic brake
- ► Establish a numerical model of the hydrodynamic brake
- ► Integrate the brake model with the coupled model of the floating vertical axis floating turbine
- ► Evaluate the effect of the hydrodynamic brake
- ► Dynamic analysis of the floating vertical axis wind turbine with the hydrodynamic brake during shutdown situation

A floating vertical axis wind turbine with hydrodynamic brake



5 MW DeepWind rotor



OC4 semi-submersible

Hydrodynamic brake: four flat plates attached to the centre column

Modeling of the floating vertical axis wind turbine

RIFLEX wind turbine
Structural analysis of slender, flexible beams
(Mooring lines, tower and blades)

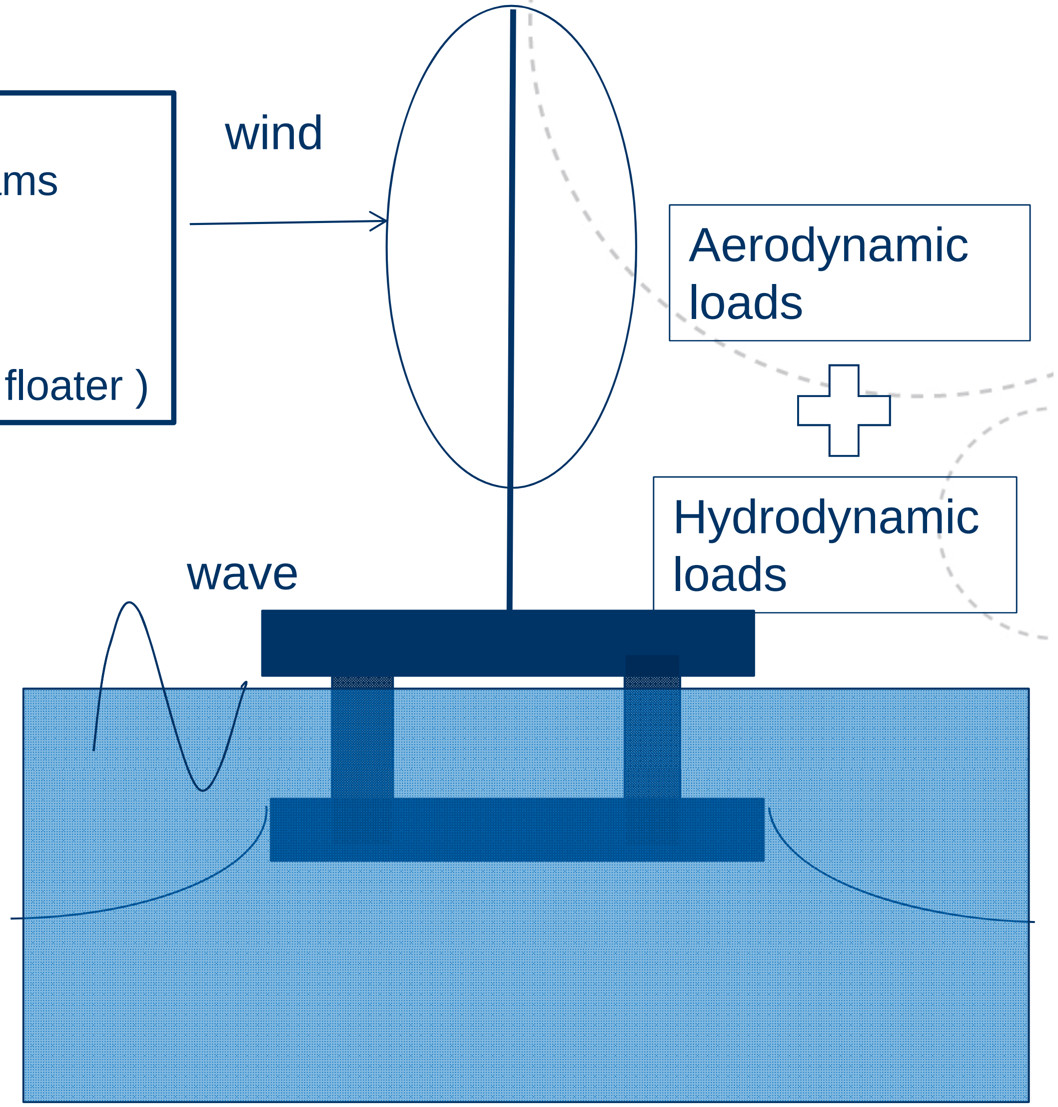
SIMO
Motion analysis of floating structure (rigid floater)

+

Aerodynamic loads provided through
Dynamic Link Library (DLL)

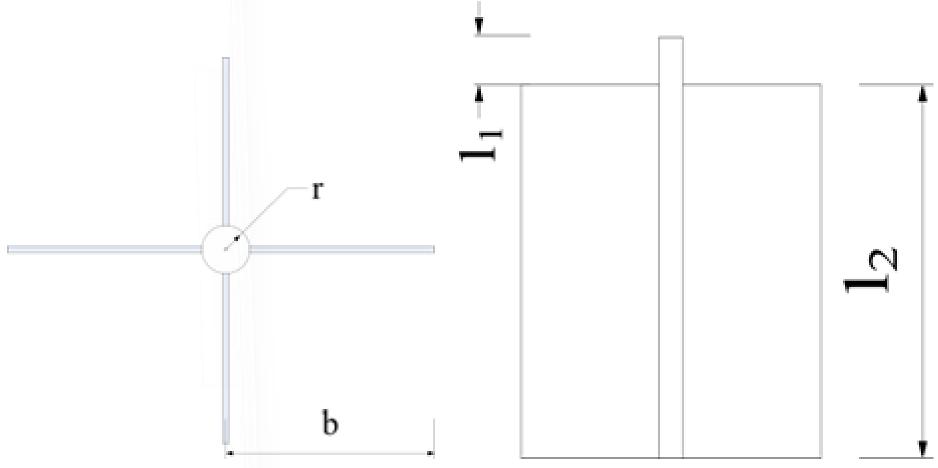
=

Fully coupled model



Modeling of the hydrodynamic brake

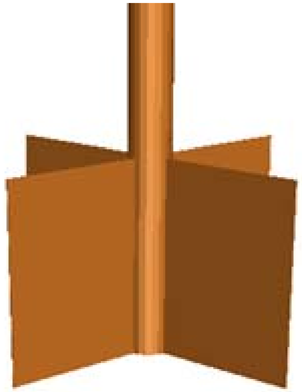
- Preliminary design of hydrodynamic brake
- Modeling as a slender beam
- Hydrodynamic coefficients
- Determination of the torque from drag force on the plate



	Hydrobrake I		Hydrobrake II	
	Colomn	Plate	Colomn	Plate
Raduis/Width (m)	1.5	11	2	16
Length (m)	38.494	36	30.494	28
Thickness (m)	0.02	0.083[a]	0.02	0.083[b]
Weight (N)	551509.2	3506517.8	583500.1	4765248.1
Bouyancy (N)	2736013.9	1321983.8	3853160.8	1495577.7

[a] Sum of the hollow thickness and plate thickness of 0.014 m

[b] Sum of the hollow thickness and plate thickness of 0.017 m



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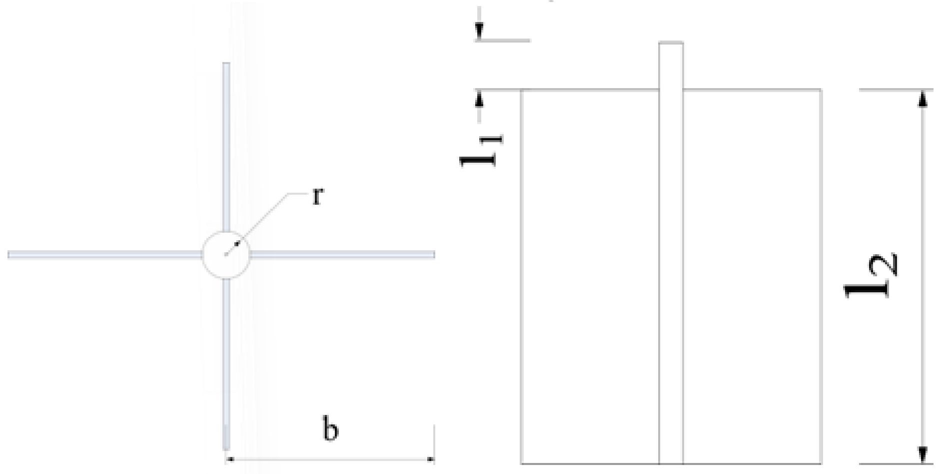

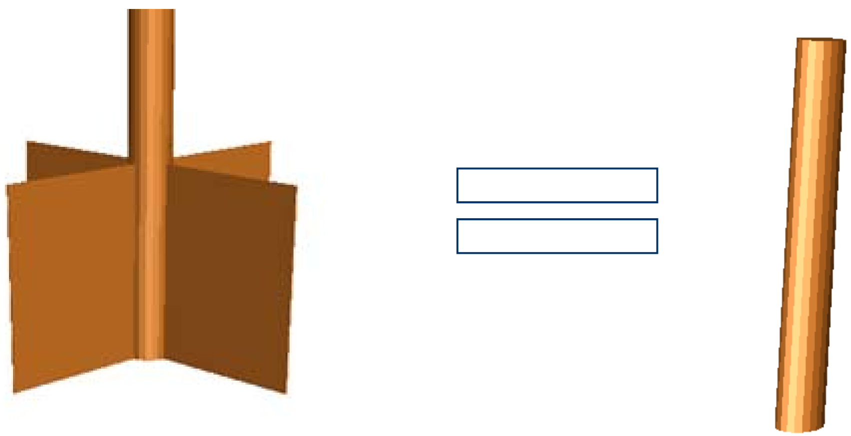

Modeling of the hydrodynamic brake

(1)

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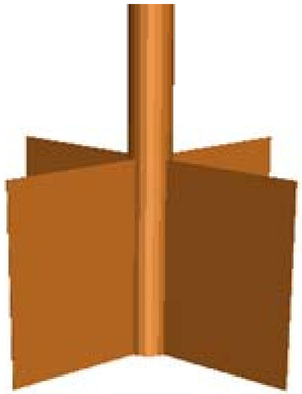


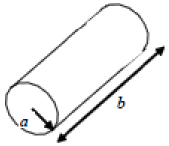
Added mass

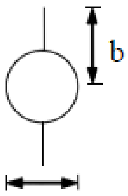
$$m_A^{hor} = \rho(1-(r/b)^2+(r/b)^4)\pi b^2 l_2$$

$$m_A^{ver} = \rho C_A^{ver} \pi r^2 l_2$$

Drag coefficient

Cd= 1.9

			$b/2a$	C_A
Right circular cylinder	 	Vertical	1.2 2.5 5.0 9.0 ∞	0.62 0.78 0.90 0.96 1.00

 	Circular cylinder with two fins	Vertical	1.0	πa^2
		Horizontal	$1-\left(\frac{a}{b}\right)^2+\left(\frac{a}{b}\right)^4$	πb^2

Det Norske Veritas, ENVIRONMENTAL CONDITIONS AND ENVIRONMENTAL LOADS, Tech. Rep., DNV-RP-C205 (2007).

Modeling of the hydrodynamic brake

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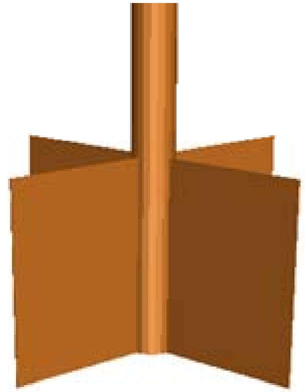
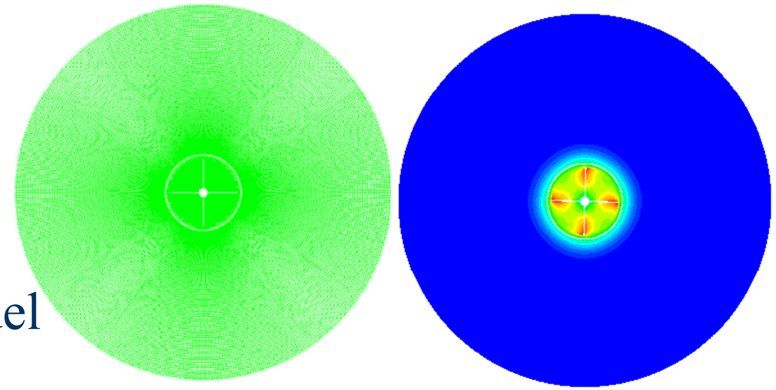


CFD simulation:

- 2D sliding mesh model
- first-order upwind
- absolute velocity formulation
- renormalized Group (RNG) k-ε turbulence model
- standard wall function for near-wall treatment
- grid mesh
  135900 inner region
  24640 outer region
- time step 0.1 s



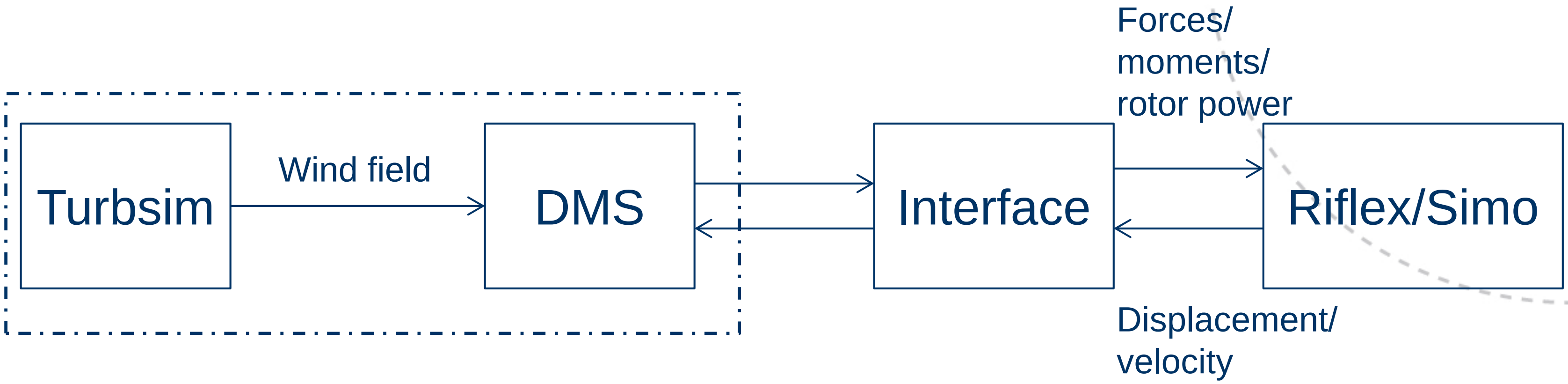
Brake I

$$T_q = -20229\omega^3 + 125338\omega^2 - 30925\omega + 2680.2$$

Brake II

$$T_q = 123523\omega^3 + 21286\omega^2 + 9917.4\omega + 19.624$$

Simulation tool: Simo-Riflex-DMS



Dynamics of fully coupled model

❖ Aerodynamics

Double Multiple-Streamtube model (DMS) and BL dynamic stall model.

❖ Structural dynamics

The structural dynamics of the rotor, mooring lines and brake is calculated by the nonlinear finite element solver in RIFLEX (developed by MARINTEK).

❖ Hydrodynamics

The floater motion is simulated according to linear hydrodynamic theory plus viscous term of the Morison formula in SIMO.

❖ Wind turbine control

A PI controller is designed for generator torque.

Environmental and shutdown conditions

	Uw (m/s)	Hs (m)	Tp (s)	Turb. Model	Fault Configuration	Sim. Length
LC 1	8	2.55	9.86	NTM	A, B, C, D	2800
LC 2	10	2.88	9.98	NTM	A, B, C, D	2800
LC 3	14	3.62	10.29	NTM	A, B, C, D	2800
LC 4	18	4.44	10.66	NTM	A, B, C, D	2800
LC 5	22	5.32	11.06	NTM	A, B, C, D	2800
LC 6	25	6.02	11.38	NTM	A, B, C, D	2800

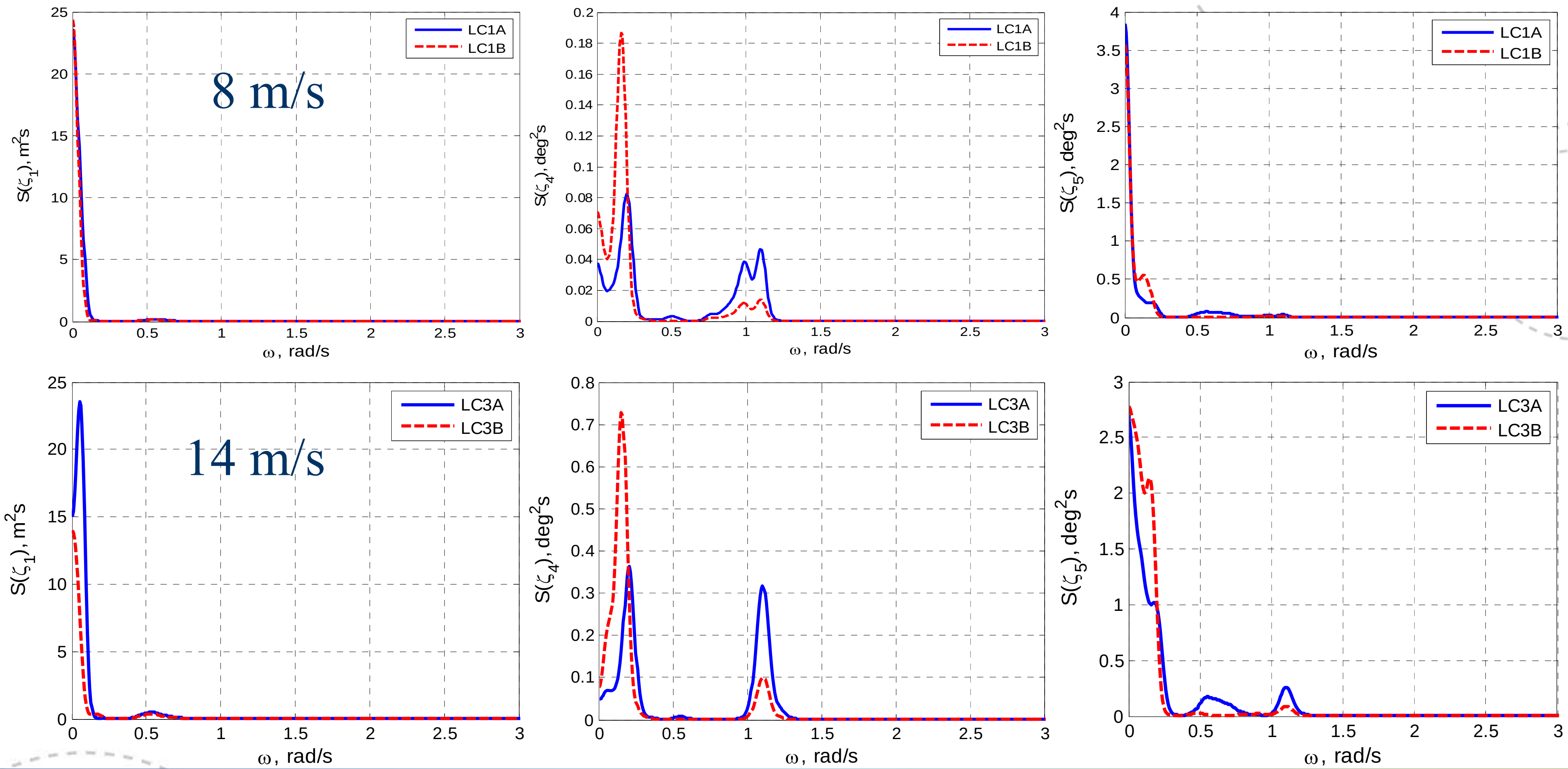
A) The original FVAWT without hydrodynamic brake and no fault happen
B) The FVAWT with hydrodynamic brake I and no fault happen
C) The FVAWT with hydrodynamic brake I and fault happen followed by free rotation
D) The FVAWT with hydrodynamic brake II and fault happen followed by shutdown

The accidence of grid loss was assumed to happen at time TF = 1200 s
The hydrodynamic brake was connected to the rotating shaft to initiate the shutdown process by a short time delay TD = 1 s.

Effect of the hydrodynamic brake I

A selection of results:

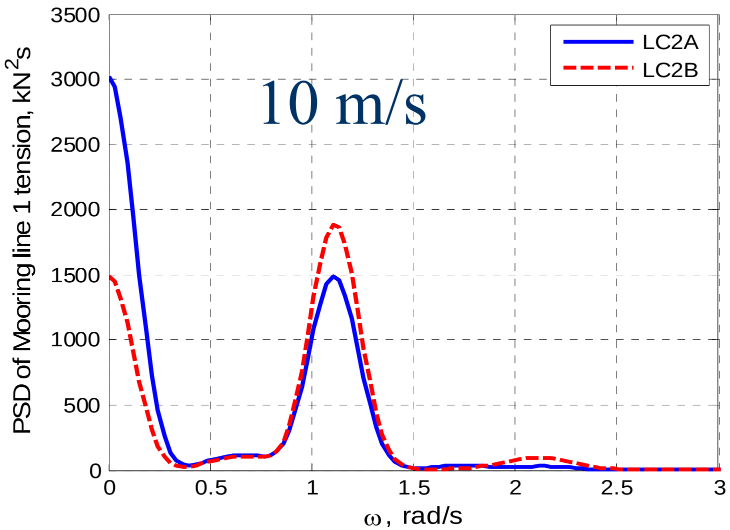
- Surge motion
Roll motion
Pitch motion

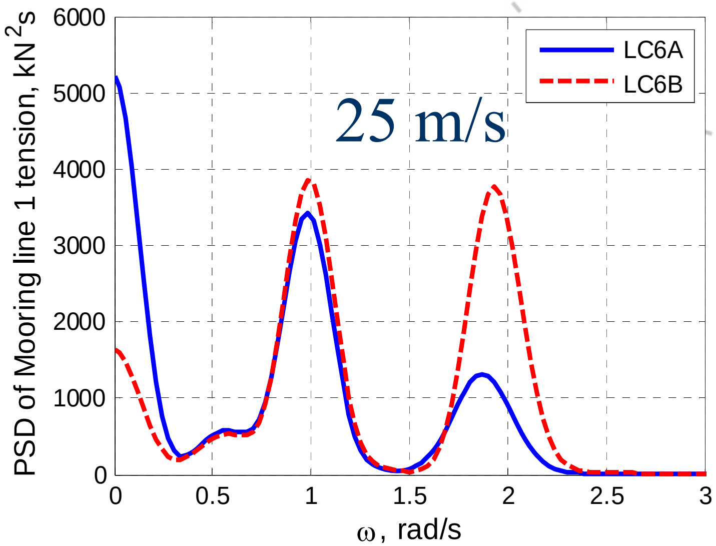


Effect of the hydrodynamic brake I

A selection of results:

➢ Mooring line tension

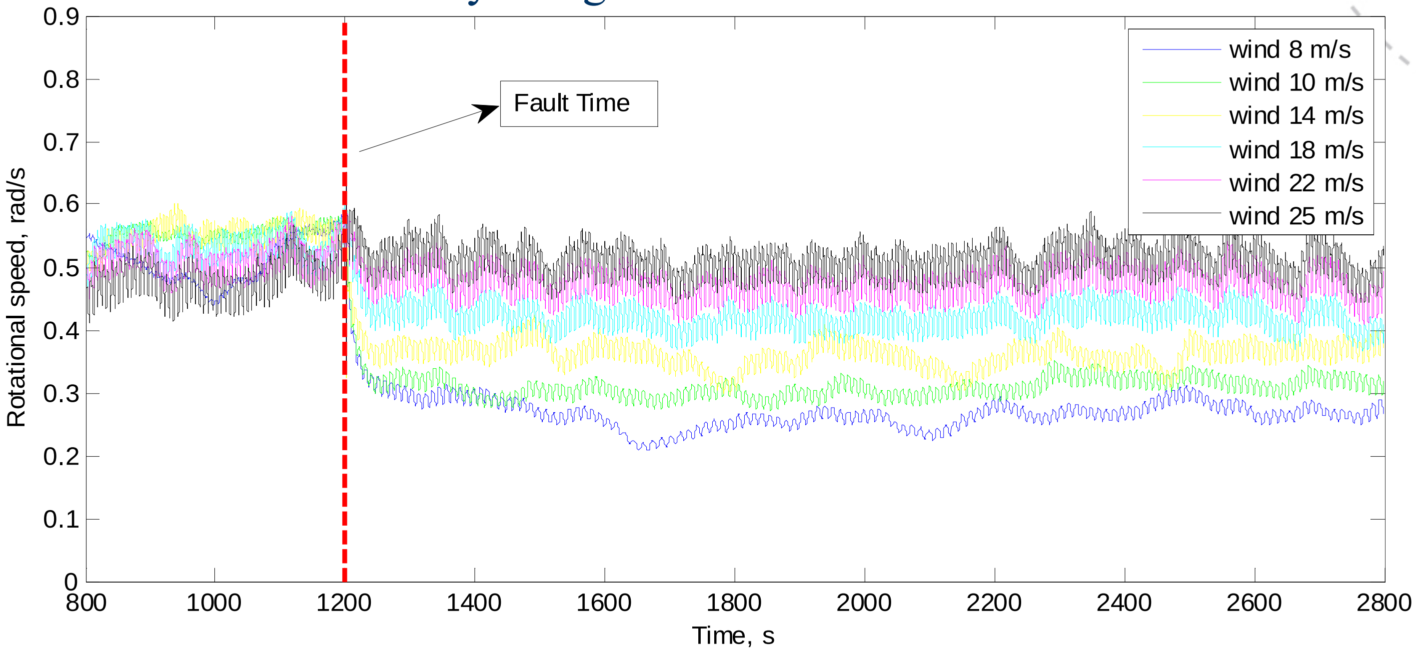




- The brake could significantly reduce the mooring tension response from the wind excitation, whereas it makes larger peak at higher frequencies.
- Besides the peak at the 2P frequency, another peak at the higher frequency was found and it should be induced by the eigenfrequency of the blade.
- With the increase of wind speed, the peak induced by structural eigenfrequecy is more apparent.

Analysis of emergency shutdown by using the hydrodynamic brake I

Time history of rotational speed for different wind speed after fault occurs at TF=1200 s by using brake I

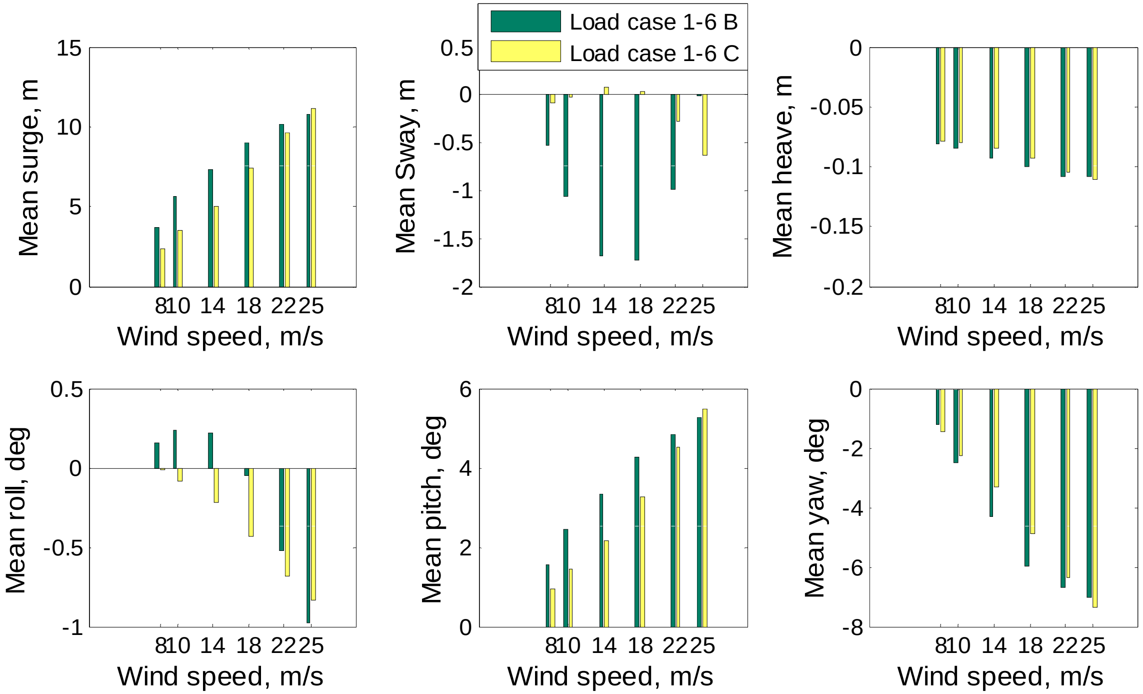


- Once the hydrodynamic brake takes effect to counter the aerodynamic torque, the rotation speed varies depending on the balance of aerodynamic torque and hydrodynamic torque
- The brake I does not give enough torque to stop the rotation, but it could avoid the overspeed of the rotor.

Analysis of emergency shutdown by using the hydrodynamic brake I

Global motion

fault configuration B vs. fault configuration C



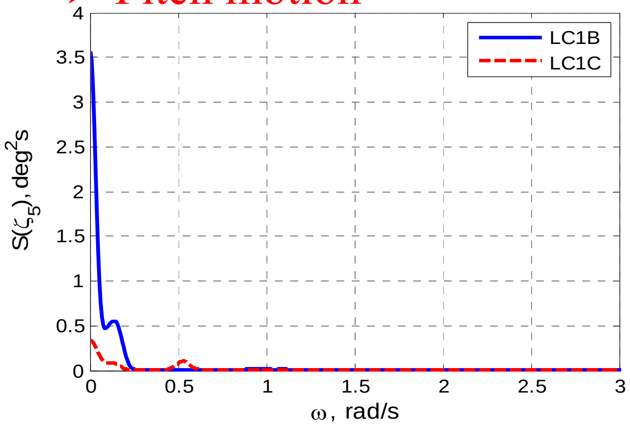
Different wind speeds

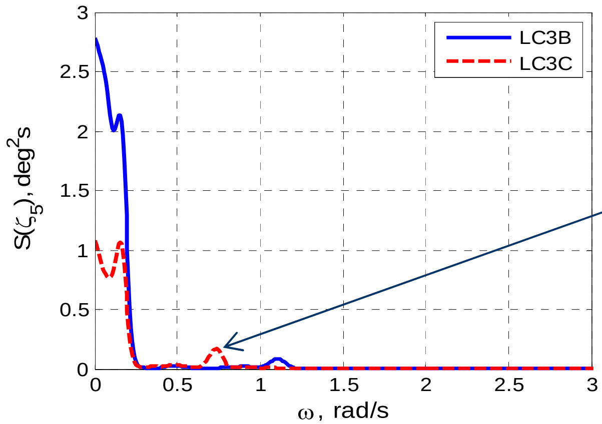
• The global motion of the platform shows better performance, which contributed from the decreasing rotational speed after the hydrodynamic brake initiates.

• Surge and pitch motion can get much more advantages while the sway and roll motions have got both good and bad effects from different load case.

Analysis of emergency shutdown by using the hydrodynamic brake I

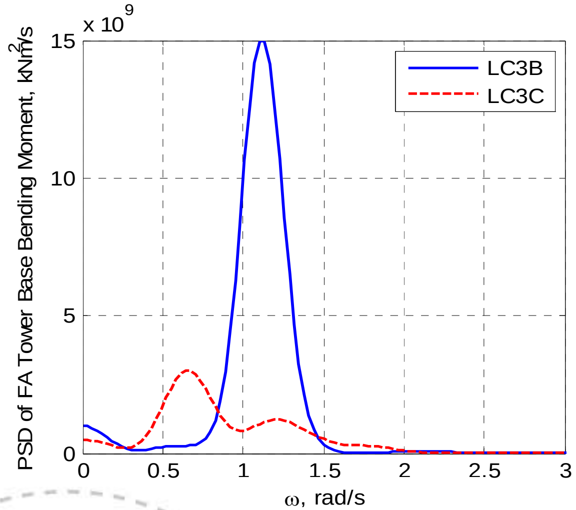
➢ Pitch motion

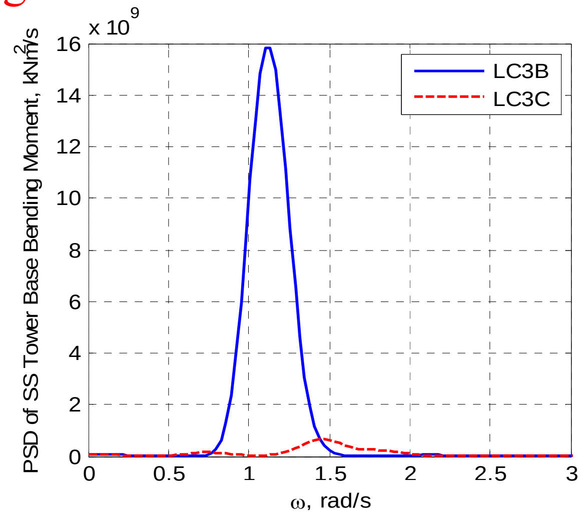




- The less wind speed, the more pitch motion reduced.
- The peak at the 2P frequency was still presented, but the 2P frequency was reduced to a lower value

➢ Fore-aft and Side-side bending moment of shaft base

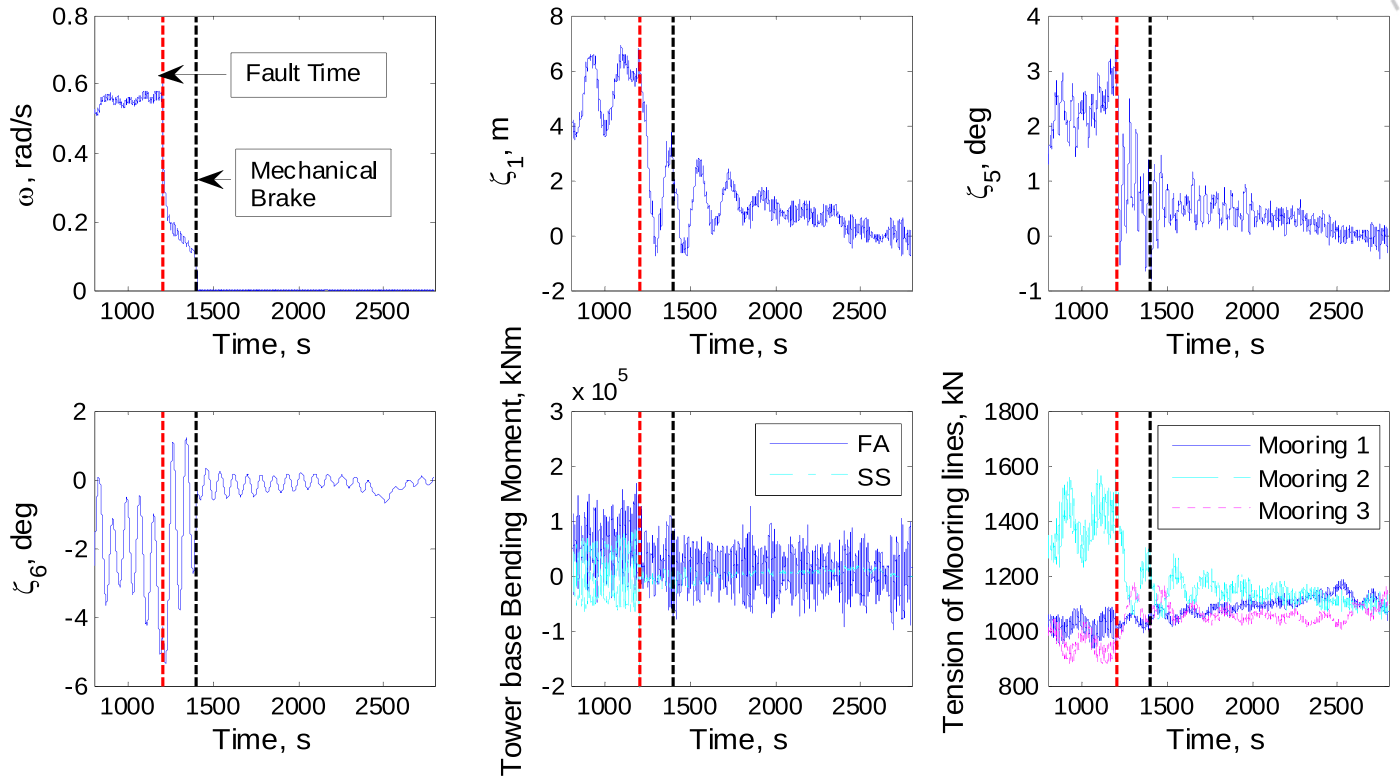




The initiation of the brake with the rotating shaft of the wind turbine together could mitigate the 2P effect and then the wave frequency excitation dominates the response of FA tower base bending moment

Shutdown process by using the hydrodynamic brake II and mechanical brake

Global platform motion, bending moment and mooring line tension



Load case 2D
V=10 m/s

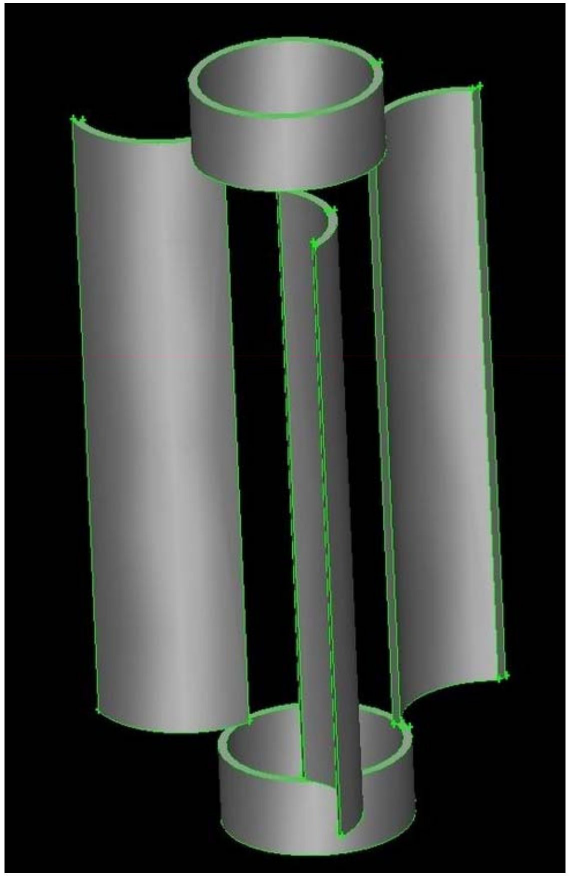
Fault occurs at TF=1200 s followed by using brake II and by using mechanical brake at 1400s

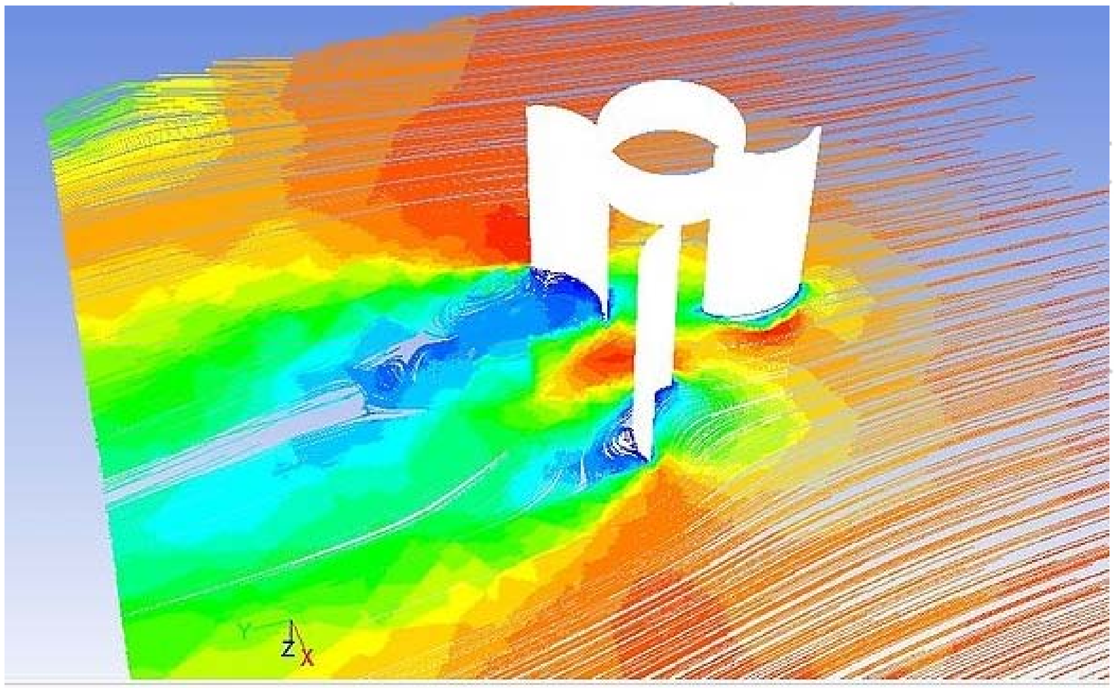
Concluding remarks

- An integrated model of a floating vertical axis wind with a hydrodynamic brake was established to carry out the non-linear time domain simulation
- The effect of the hydrodynamic brake on the FVAWT was evaluated by comparing the FVAWT with the hydrodynamic brake I to the original FVAWT
- A series of promising results indicate the merit of the hydrodynamic brake used during emergency shutdown
- Combing a mechanical brake with a larger hydrodynamic brake, the shutdown could be successfully achieved.
- The application of hydrodynamic brake is expected to be efficient and promising for the emergency shutdown and reduce the platform motion and structural loads.

Future work

A more efficient brake is more attractive and promising.





http://www.cd3wd.com/cd3wd_40/ap/Optimization_and_CFD_analysis_of_wind-powered_water_pump_system.html

Thank you for your attention!