# Coupled Analysis of a Spar Floating Wind Turbine considering both Ice and Aerodynamic Loads

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## Objectives and scope

A model is proposed for establishing the **Coupled Analysis of a Spar Floating Wind Turbine considering both Ice and Aerodynamic Loads**. This topic is important within the field of renewable energies research given that among renewable energies, wind energy has known one of the fastest growths. And, in the case of cold climate regions such as the Baltic Sea, ice loads become an important point to consider in the design of offshore wind turbines. The central issue to be addressed within this work is the coupled action of ice and aerodynamic loads on a **Spar floating wind turbine**. The following tasks should be addressed in the thesis work:

1. Study and develop the coupling between the ice load DLL and HAWC2, the aero-hydro-servo-elastic simulation tool .
2. Based on the existing data of the 5MW spar wind turbine, perform coupled time-domain simulations considering only ice loads and a sensitivity study for different ice drift speed and thickness. Compare the results of uncoupled and coupled analyses.
3. Perform analyses with both ice and wind turbine loads.

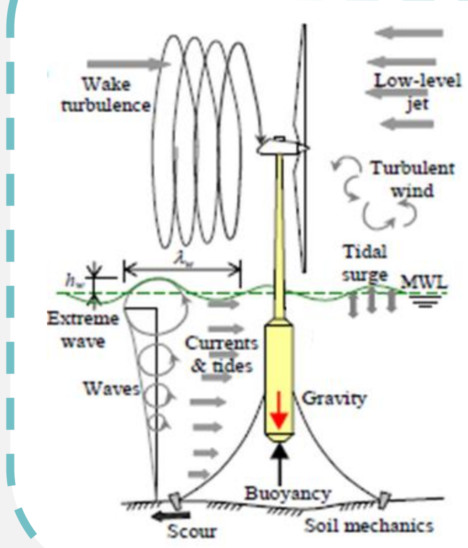
## Introduction

In the past years, the energy consumption has increased along with Global warming concerns while fossil-based energy resources have been depleting. In this context, thorough investigations have been run to find ways to counter the energy problem by exploiting renewable energies and develop their use. Among those renewable energies, wind energy has known one of the fastest growths. The present study will focus on a spar floating wind turbine. A spar wind turbine presents good heave motions performances, small wave forces and are, among other things, easy to install and cheap to build and maintain compare to other types of wind turbines ( Biswajit, et al., 2013). All of these features make this type of structure well suited for deep water operations where the production is the most promising given the encountered wind conditions i.e. strong and constant wind.

Floating wind turbines can be really challenging structures for modelling processes due to large rotational and translational motions of the structure and modeling of mooring and anchoring systems. However, they have been studied extensively in the literature due to their suitability for wind energy production in deep water. However, the most suited sites to install offshore wind farms might potentially be subjected to ice conditions and so far few researchers have studied the importance of these loads compared to the aerodynamic ones in the case of spar wind turbines. The purpose of this project is to perform dynamic response analyses of a spar wind turbine under ice loads for design check, and to investigate the importance of ice loads on the floater. To do so, we have implemented a semi-empirical ice load module coded in Fortran into the aero-hydro-servo-elastic tool HAWC2 (Larsen, et al., 2007). The structure is fitted with an inverted cone at the mean sea level (MSL) to mitigate the ice loads. A rigid model is implemented to study the influence of ice drifting speed, ice thickness and study the relative importance of aerodynamic and ice loads in the case of a coupled analysis.

## Modelling

### Aero-hydro-servo-elastic model




NREL offshore 5-MW WT installed on a floating spar-buoy in deep water (320m)

HAWC2 software with the following features:

- Structural formulation
- Aerodynamic model
- Hydrodynamic model
- Water kinematics
- Soil module
- Wind turbulence and wake models
- Connection to turbine controllers

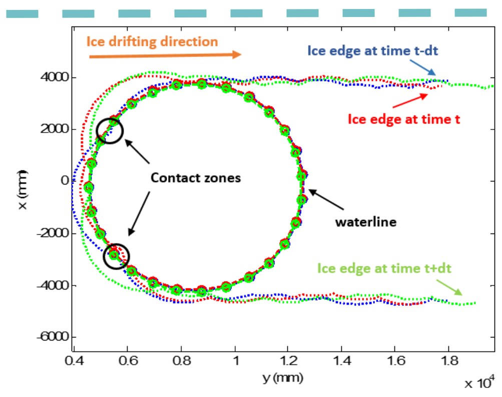
Position, Velocity →

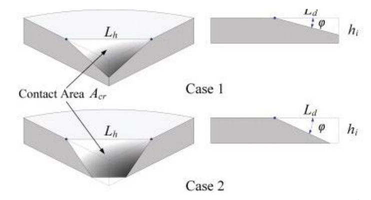
← Forces, Moments

### Ice loads model

1. **Discretization** of the waterline of the wind turbine and the ice edge (See figure) taking into account the variations due to the 6 DOFs motions of the wind turbine
2. **Detection of overlaps** in the 2 geometries and **contact area** estimation (See figure)
3. **Local crushing forces** are calculated: $F_{cr} = p_{av}A_{cr}$
4. **Contact loads** obtained by integrating the local forces over all the contact zones
5. Contact loads compared to the **bending failure criterion** to find when the ice will break
6. Size of the broken ice flow and the **ice breaking pattern** determined by idealizing the bending crack as a circular arc

See (Tan, et al., 2013), (Su, et al., 2011) for more details

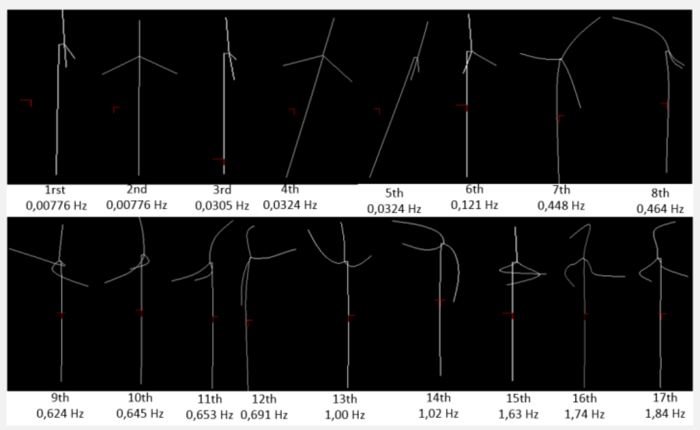


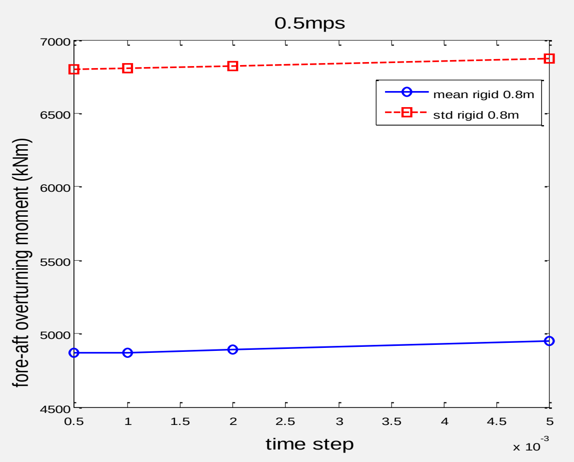



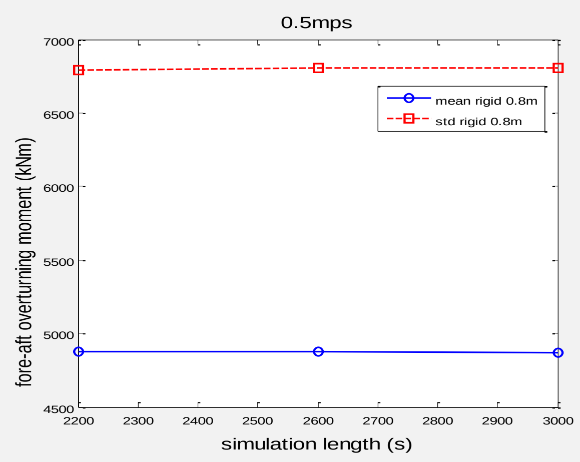

- The problem should be studied in time domain given the non-simultaneous failure of the ice around the structure. Thus, iterations are needed to find the updated parameters at each time steps.
- Numerical issues were encountered due to the large rotational and translational motions of the structure but they were solved by introducing the ice loads using a ramp function sufficiently long

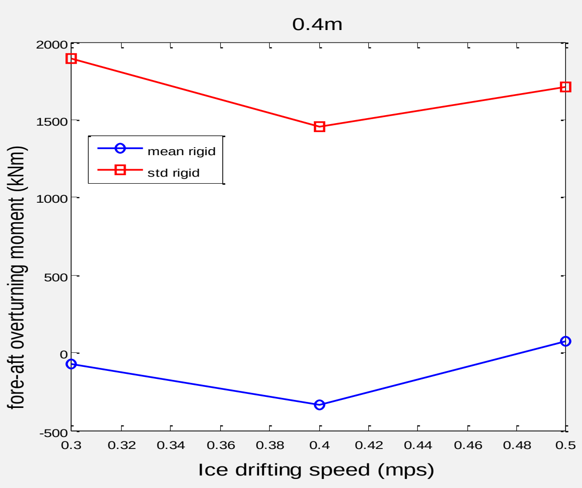
## Simulation results

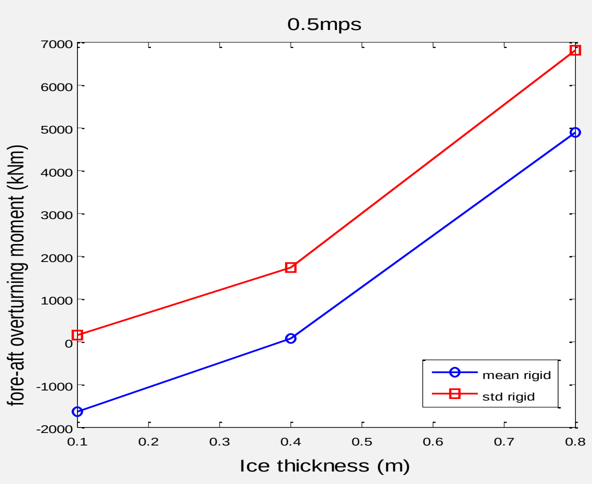
1. An **eigenfrequency analysis** and a **convergence study** have been conducted to gain knowledge on the system and the simulation parameters (time step and simulation length)
2. A comparison of the **coupled model and the decoupled model** used so far for the spar floating wind turbine study has been conducted
3. A study of the **ice breaking pattern** depending on the ice properties (thickness and drifting velocity) has been done
4. A sensitivity study for different **ice drifting speed and thickness** has been run (no wind)
5. A comparison of **aerodynamic and ice loads** has been conducted

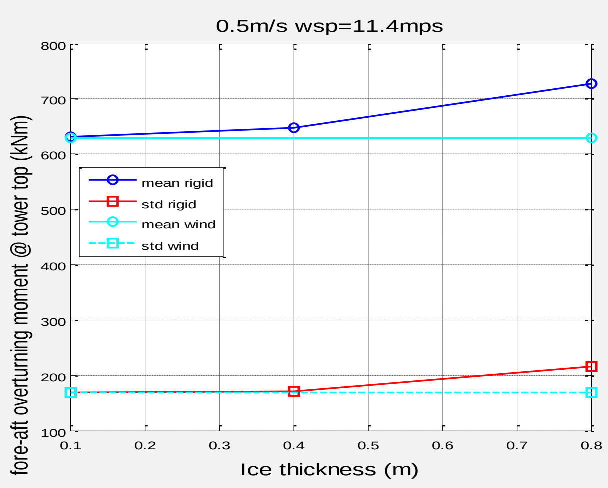


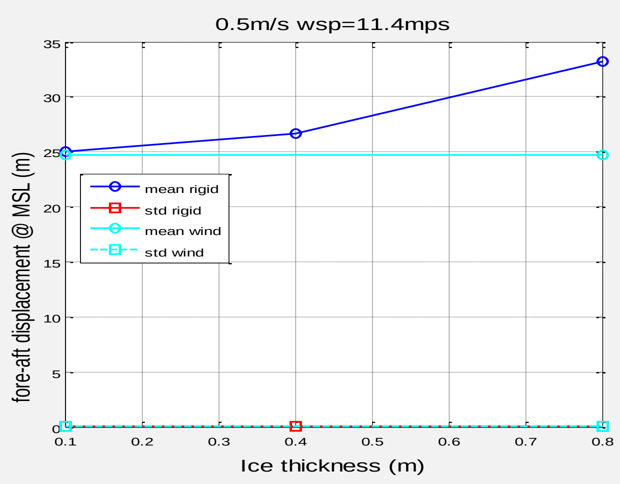



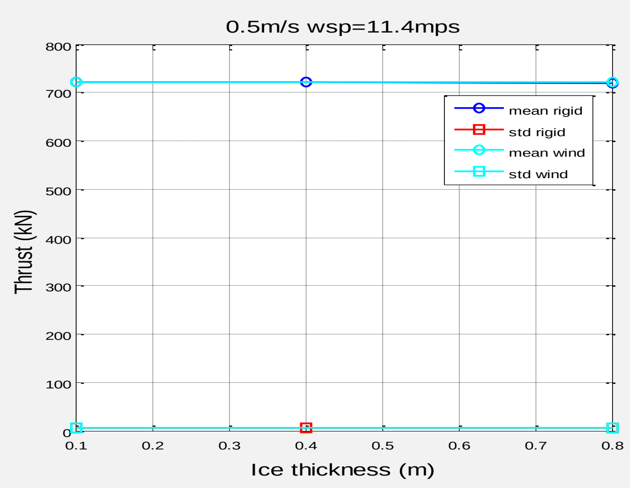




## Conclusion and recommendations

**Coupled model vs. decoupled model:**

- Present differences in magnitude but comparable output shapes with larger difference observed for high drifting speed or large ice thickness
- Difficult to identify a clear trend in the difference in results

**Only ice loads – with constant ice properties:**

- Simulations have highlighted the influence of the ice drifting speed and thickness in the ice breaking pattern and the structural responses
- Increasing ice thickness induces increasing loads: increasing ice thickness will increase the contact area, and consequently induces higher ice loads.
- A trend is hardly discernable for the influence of ice drifting speed and it has a less significant influence on the dynamic response than ice thickness.

**Constant wind and ice loads – with constant ice properties:**

- The wind has a predominant influence on the loads.
- Ice loads participate to the dynamic component of the response: influence in fatigue damages but the power production does not seems to be impacted

**Future work:**

- More load cases should be run with both ice and wind loads. Indeed, only a limited number of results were obtained in this work.
- Analysis should be performed with both random variation of ice properties and turbulent wind field. Then fatigue and energy production study can be run in more realistic conditions and can be used for design purpose.
- The accuracy of the results obtained should be assessed whether by standards and guidelines, by comparing the model with a model developed in another university or by comparing them to physical response data from actual measurements (model tests or full scale data).

## References

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