

FAST simulations of drifting sea ice loads on offshore wind turbine support structures

Jaakko Heinonen and Simo Rissanen

VTT Technical Research Centre of Finland LTD, Espoo, Finland

The Baltic Sea features a potential for large capacity wind farms because of relatively high and constant wind velocities and mostly shallow coastal regions enabling cost-efficient foundation and grid connection. However, in the northern sea area - Gulf of Bothnia - the sea freezes annually and the sea ice must be considered in the design of offshore structures. Ice loads and ice-induced vibrations due to drifting ice field introduce the most significant uncertainties in the support structure design for offshore wind turbines.

The magnitude and time variation of ice load depends on various factors, like the thickness and velocity of the ice as well as the size and shape of the structure. The failure mechanism of ice is strongly governed by the shape of the structure at the water level. Sloped shapes like a cone induce the ice to fail by bending as vertical shapes cause the ice to fail by crushing. It is commonly known that by implementing a monopile with a cone is a suitable way not only to reduce the ice load magnitude, but also to avoid severe ice-induced vibrations. However, both the foundation costs and wave loads in terms of additional material at the water level increase owing to the implementation of the cone.

Regarding slender monopile structures the flexibility at the water level plays a major role in ice-induced vibrations. A coupled interaction with the structural deformations and ice load is required for the simulation of structural performance. To get a better understanding of ice induced vibrations in offshore wind turbines, a simplified ice load model was developed referring to assumptions given by Matlock et al. (1969) and Withalm and Hoffmann (2010). The model is able to determine a dynamic ice load with a dependency on the ice conditions (thickness and velocity) and structure (dimensions and deflection). The ice load model was implemented into a software FAST (Fatigue, Aerodynamics, Structures and Turbulence) developed by National Renewable Energy Laboratory in the USA for simulating the coupled dynamic response of wind turbines. The main objective was study the feasibility of the FAST simulation software in the structural performance studies of offshore wind turbines under coincident ice and wind loads.

Feasibility studies were carried to compare in-house ice load model with IceFloe module available in FAST version 8. The structural model was based on the NREL offshore 5-MW baseline wind turbine with a monopile type of support structure. Different structural configurations and load cases were studied. Water depths were varied between 10 and 30 m and sea ice parameters were selected to correspond typical ice conditions at Gulf of Bothnia by varying the ice velocity and thickness. Special attention was paid for studying combined load from the ice and wind in terms of different operation modes of the turbine (idling vs. production). These configurations were investigated to point out how the dynamic ice loads against a flexible structure depend on the site selection, ice conditions and operational mode. In addition, displacement response at various locations like at the nacelle and at the blade tip was studied to gain deeper understanding about the severity of ice-induced vibrations.

As a conclusion, a coupled modelling of ice-structure interaction is a necessary step to improve the accuracy of the ice load evaluation for the cost-efficient structural design. With the presented model, more understanding was gained compared to common standards in terms of ice-induced vibrations.