Comparison of numerical response predictions for a bottom fixed offshore wind turbine

Stian Høegh Sørum[(a,b)], Jan-Tore H. Horn[(a,b)], Jørgen Amdahl[(a,b)]
[(a)]Centre for Autonomous Marine Operations and Systems (NTNU AMOS),
[(b)]Department of Marine Technology, NTNU, Trondheim, Norway.
Email: stian.h.sorum@ntnu.no

NTNU AMOS
Centre for Autonomous Marine Operations and Systems

Introduction

A large number of software codes are available for the analysis of offshore wind turbines. Due to the limited availability of full-scale measurements, verification of the codes are often done by code-to-code comparisons. Here, the codes SIMA from MARINTEK, vpOne/USFOS from Virtual Prototyping and FAST v8 from NREL are compared. The response to a selection of load cases are calculated, before a fatigue analysis is performed.

Program capabilities

The programs used have different capabilities for calculating loads and response. All codes calculate the hydrodynamic loads using Morrison's equation, while the differences in utilized mode capabilities are given below. In addition, there are differences in the engineering corrections applied to the BEM calculations.

	SIMA	vpOne	FAST
Aerodynamic loads	Steady BEM	Steady BEM	Unsteady BEM
Hydrodynamic stretching	Wheeler	Wheeler	None
Soil model	Non-linear springs	Non-linear springs	Equivalent beam
Strucutral model	Finite element model	Finite element model	Modal model

Models

The modelled turbine is based on the DTU 10 [MW] reference turbine [1, 2]. To reduce the frequencies of the 1st tower modes, the tower wall thickness is increased with 20 %, and the blades are modified as given in [3]. The foundation is of the monopile type, with a diameter of 9 [m] and wall thickness of 0.11 [m].

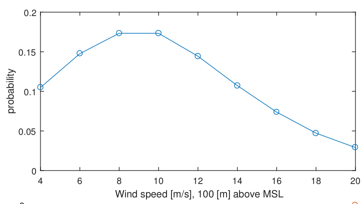
While the structure is modelled using FEM in both SIMA and vpOne, a modal model is used in FAST. The two first tower modes in fore-aft and side-side direction are modelled, as well as the two first flapwise modes and first edgewise mode of the blades. The natural frequencies of the models are given below:

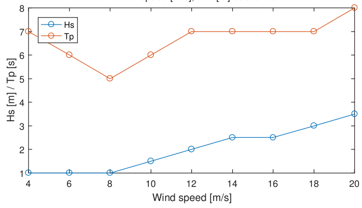
Mode	Frequency range
1st tower side-to-side	0.226-0.227 [Hz]
1st tower fore-aft	0.228 [Hz]
1st blade asym. flap (yaw)	0.563-0.564 [Hz]
1st blade asym. flap (pitch)	0.592-0.594 [Hz]
1st blade collective flap	0.624 [Hz]
1st blade asym. edge 1	0.946-0.951 [Hz]
1st blade asym. edge 2	0.950-0.957 [Hz]
2nd tower side-to-side	1.241-1.303 [Hz]
2nd tower fore-aft	1.183-1.189 [Hz]
2nd blade asym. flap (yaw)	1.460-1.466 [Hz]
2nd blade asym. flap (tilt)	1.682-1.715 [Hz]

Analysis Parameters

A number of analysis types have been run to investigate the predicted responses. Here, two analyses are presented. The first is the steady state response of the turbine as a function of wind speed. For steps of 0.5 [m/s] the turbine response with all degrees of freedom enabled has been calculated, to give an overview of the basic aerodynamic properties and structural response.

The fatigue analysis was performed in operational conditions using bin sizes of 2 [m/s] for wind speed and the most probable significant wind speed and wave height for each wind speed. Metocean data were provided for the Dogger Bank area[4]. Wind turbulence is assumed to be of class B, while all waves are assumed to be long crested and travelling in the same direction as the wind. The analysis parameters are shown below.



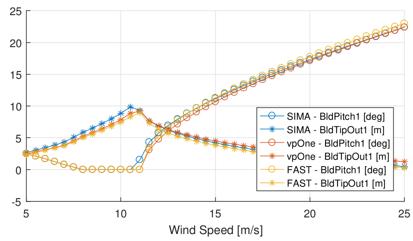


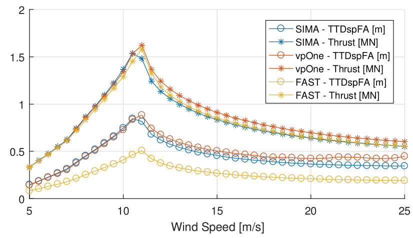
Results

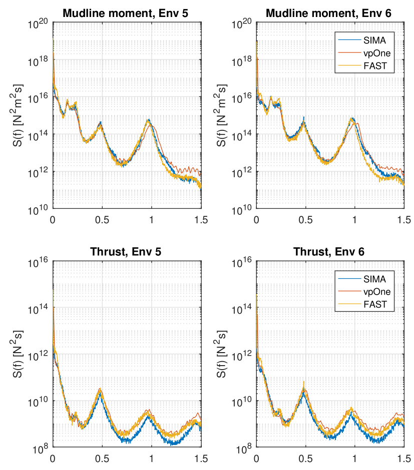
The steady state analysis yielded similar results for all codes, with a few exceptions. For wind speeds above rated, both vpOne and FAST predicts a higher thrust force than SIMA, with a decreasing difference as the wind speed increases. This is partially caused by the controller in SIMA pitching the blades more than the other codes.

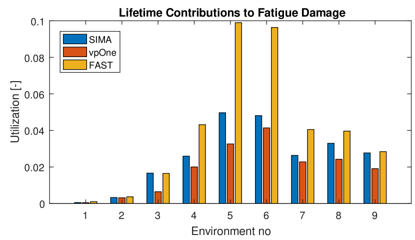
Furthermore, the equivalent beam in FAST is tuned to give the correct natural frequency, without regard to the displacement and rotation at mudline. This may again influence the aerodynamic damping due to reduced motions of the tower top.

The fatigue analysis shows a significant difference in the predicted utilization of the structure, evaluated at mudline. Especially for high aerodynamic thrust, the difference is clearly visible. Here, FAST predicts clearly larger damage than the two other codes. An explanation can be provided by investigating the thrust and mudline moment spectra for these environmental conditions. In the thrust spectrum, FAST can be seen to have a larger response amplitude at the low frequency end of the spectrum, as well as larger response at the 1st natural frequency of the tower and at the peak frequency of the wave spectrum. This indicates that the provided aerodynamic damping is to low in FAST, and that this is cause for the increased predicted fatigue utilization. Similarly, the reduced utilization in vpOne is believed caused by an increased aerodynamic damping, both of the first and second tower modes.









With the larger utilization predicted by FAST, the importance of correct representation of the soil data is demonstrated. However, there is also a large difference between SIMA and vpOne. These programs are quite similar in capabilities and steady-state responses, and show that there can be a large difference in the response predicted by the codes.

References

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