Harnessing Natural Energy

Multiple simulation tools are used as a cost-effective way to design reliable offshore wind turbines.

By Fabian R. Vorpahl, Holger Huhn and Hans-Gerd Busmann, Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT), Bremerhaven, Germany
Stefan Kleinhansl, Aero Dynamik Consult GmbH, Neuhausen/Stuttgart, Germany

Image courtesy REPower

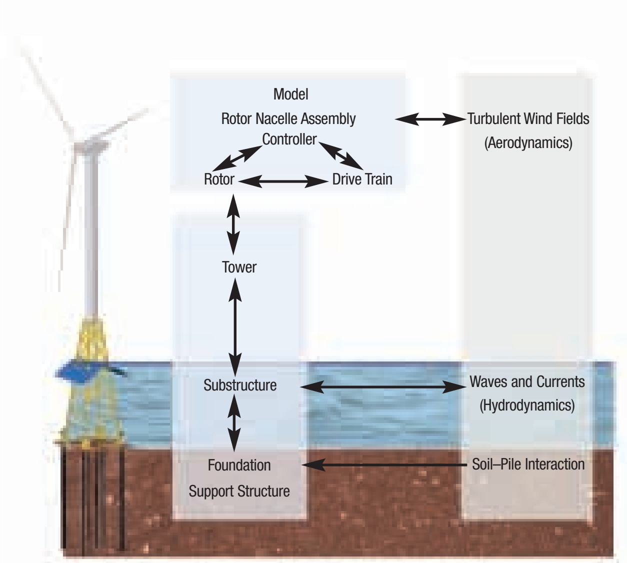
Governments around the world are looking to offshore wind power because of its potential as a reliable source of inexpensive, renewable energy. However, developing wind farms in a marine environment comes with a new set of engineering challenges. The support structures for these offshore wind turbines (OWTs), for example, must be designed to function effectively in deep water and with large turbines. Offshore projects also present challenges to design engineers, manufacturers and operators because storms, rough seas and saltwater subject the entire turbine and its associated support structure to extreme stresses. Engineering simulation is a valuable tool for designing cost-efficient and reliable large-frame OWTs.

To evaluate OWT designs for life expectancy and certification, detailed analysis of critical parts of the turbine is very important in order to predict fatigue. The OWTs being studied consist of a turbine and tower that are attached to a partially submerged substructure. The substructure is fastened to the ocean floor using foundation piles. In order to obtain accurate results when simulating the overall system, a number of effects must be considered simultaneously, including loads from turbulent wind fields, the turbine control system, loads resulting from waves and currents, the elastic behavior of the support structure, and the soil characteristics of the local sea bed.

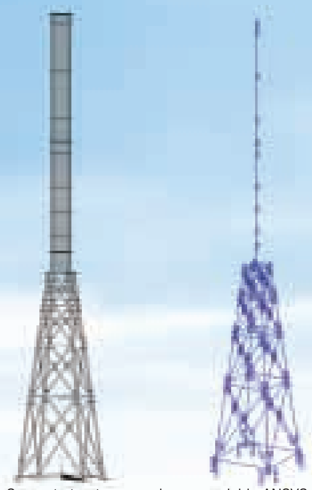
To carry out the complex simulation of OWTs with branched support structures, engineers at the Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT) used a special purpose aeroelastic software, ADCoS. This tool relates the influence of the environment (wind effect, wave type and structure, sea state and behavior of the ocean currents) and the soil-pile structural interactions, to the structural capacity of the overall wind turbine. ADCoS, developed by Aero Dynamik Consult Ingenieurgesellschaft, has typically been utilized for onshore wind turbines and has the capability to conduct a detailed investigation of interacting loads and the resulting dynamic response on an OWT. Extensive knowledge of all the load sources and their interactions can help improve the reliability of OWTs and is vital for cost-effective operation of offshore wind farms.

Before analyzing a turbine's reaction to wave loading, the CWMT engineering team needed to develop a finite element model of the entire structure. Researchers used ANSYS Mechanical software to develop and define the support structure as a parameterized beam model. Using the ANSYS-to-ASAS translator, they transferred the model to ANSYS ASAS software.

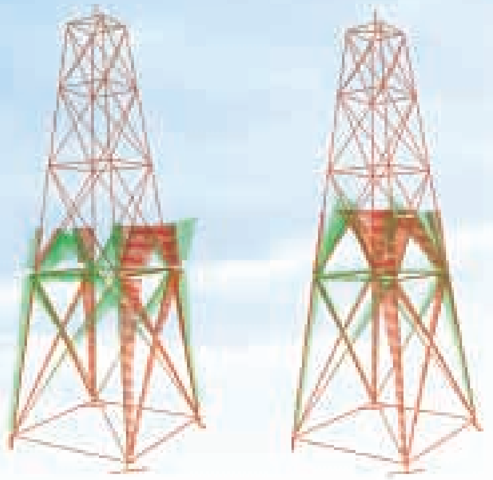
Within the ANSYS ASAS Offshore analysis tool, the engineering group used



Structure of an offshore wind turbine and loads that must be considered for simulation



Support structure as a beam model in ANSYS Mechanical (left) and in ADCoS software (right)

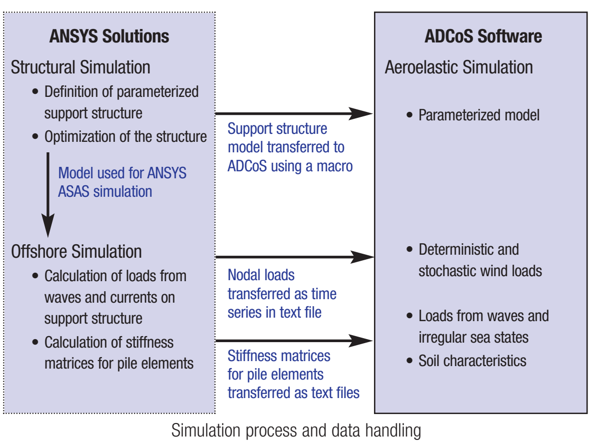


Wave loads as simulated by ANSYS ASAS software

ASAS-WAVE to calculate the wave loads on the support structure. With the aid of ASAS-WAVE, loads resulting from linear and nonlinear waves, as well as irregular sea states and currents, were taken into account. The research team calculated the loads using Morison's equation and then exported the distributed member loads, as equivalent nodal loads, into a text file for further use.

For the next step, the team conducted the nonlinear simulation of the foundation piles using the P-Y approach, as recommended by the American Petroleum Institute. This was done using SPLINTER, the soil-pile interaction tool, in the ANSYS ASAS Offshore product. SPLINTER allows simulation of single piles or pile groups, including group interaction effects via the soil medium. The outcomes of the SPLINTER analyses were linearized stiffness matrices for each pile head.

Finally the CWMT researchers performed the aero-hydro-servo-elastic (nonlinear finite element) simulation using the ADCoS software. In this step, engineers input the model created in the ANSYS Mechanical software, the wave loads from the ANSYS-WAVE tool and the stiffness matrices from SPLINTER for the pile heads into ADCoS. The modeling of the support structure, calculation of wave loads and computation of soil–pile interaction were executed using a single Windows batch file. To date, some validation has been completed, and further validation will be performed under the Offshore Code Comparison Collaboration project (OC3) within the International Energy Agency's Wind Annex XXIII.



Simulation process and data handling

In researching the interaction of wind and water with a wind turbine structure, CWMT engineers use ANSYS Mechanical functionality for creating the structural model and the ANSYS ASAS Offshore suite's extensive options to account for hydrodynamic loads and soil characteristics. The adaptive architecture of these tools allows them to be connected to ADCoS, which then enables the simultaneous aero-servo-hydro-elastic simulation of the OWT. Detailed load history information and resulting fatigue data — such as rain flow counts, load spectra and damage equivalent loads — can be derived from ADCoS. Equipped with this knowledge, CWMT can perform in-depth investigations and optimization of critical parts, leading ultimately to even more reliable and cost-effective OWTs for future wind farm projects. ■

References

[1] Jonkman, J., Butterfield, S., Musial, W. and Scott, G., "Definition of a 5-MW Reference Wind Turbine for Offshore System Development," NREL/TP-500-38060, Golden, CO: National Renewable Energy Laboratory, February 2007.

[2] Kleinhansl, S., Mayer, M. and Mangold, A. "ADCoS — A Nonlinear Aeroelastic Code for the Complete Dynamic Simulation of Offshore-Structures and Lattice-Towers," DEWEK – Proceedings, 2004.

[3] Vorpahl, F., Huhn, H., Busmann, H.-G. and Kleinhansl, S., "A Flexible Aeroelastic Simulation Approach for Offshore Wind Turbines," European Offshore Wind Proceedings, 2007, www.eow 2007proceedings.info/allfiles2/272_Eow2007fullpaper.pdf (11.06.08).

[4] Nichols, J., Camp, T., Jonkman, J., Butterfield, S., Larsen, T., Hansen, A.M., Azcona, J., Martinez, A., Munduate, X. and Vorpahl, F., "Offshore Code Comparison Collaboration within IEA Wind Annex XXIII: Phase III Results Regarding Tripod Support Structure Modeling" (to be published).

[5] http://www.cwmt.fraunhofer.de

[6] http://www.aero-dynamik.de