

Experimental Validation of a 2 MW Wind



Load calculation using multi-body simulation-codes is essential in the development of wind turbines. Furthermore, for type certification of wind turbines, a broad range of nominal and failure load cases are necessary. While in the past, simplified wind turbine codes like Flex5 have been used for that purpose, SIMPACK can also accommodate more specific detailed models. Simulation model development is supported by the SIMPACK rotorblade module and interfaces to apply aerodynamic loads from turbulent wind field models. The SIMPACK scripting environment helps the user run a large number of simulations efficiently. This article describes the experimental validation of the SIMPACK model of a newly developed 2 MW wind turbine.

WIND TURBINE PROTOTYPE AND LONG TIME MEASUREMENTS

The prototype of the 2 MW wind turbine used for model validation is characterized by the innovative drive train concept Larus Compact developed by W2e Wind to Energy GmbH (Fig. 1). Here, adverse bending moments in the drive shaft are avoided by a moment bearing for the main rotor, a flexible shaft coupling and a gearbox mount at its center of gravity. To determine interface loads, the prototype is equipped with strain gauges at the low speed shaft, blade roots, tower top and base. Further, the blade pitch angles and the angular speeds of the low-speed and high-speed shafts are measured. To observe the actual direction and speed of the wind, a measurement mast is positioned in main wind direction. Long-time measurements have been recorded under regular power production over a period of 18 months. The received data were subdivided into ten-minute time series and stored

in a capture matrix according to average wind speed and turbulence intensity.

MULTI-BODY MODEL

The SIMPACK simulation model of the 2 MW wind turbine is shown in Fig. 2 with the overall topology according to Fig. 3. The main components are tower, nacelle, blades and drive train. Tower and blades are modeled elastically. The tower is defined in ANSYS using a script written in the ANSYS Parametric Design Language (APDL). The blades with necessary coordinate systems used to apply aerodynamic loads are defined via the SIMPACK rotorblade module. The FE models are modally reduced by means of the Craig-Bampton method.

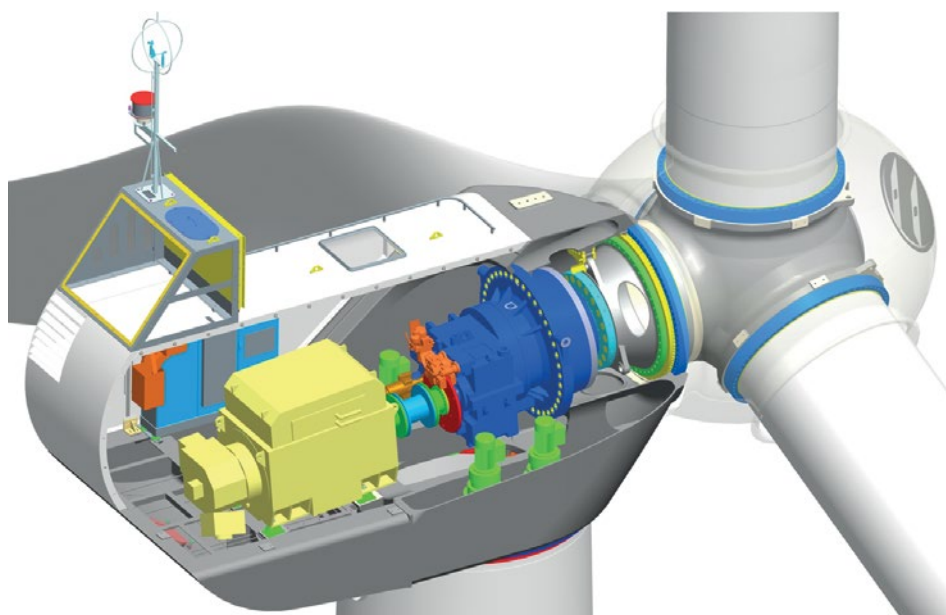
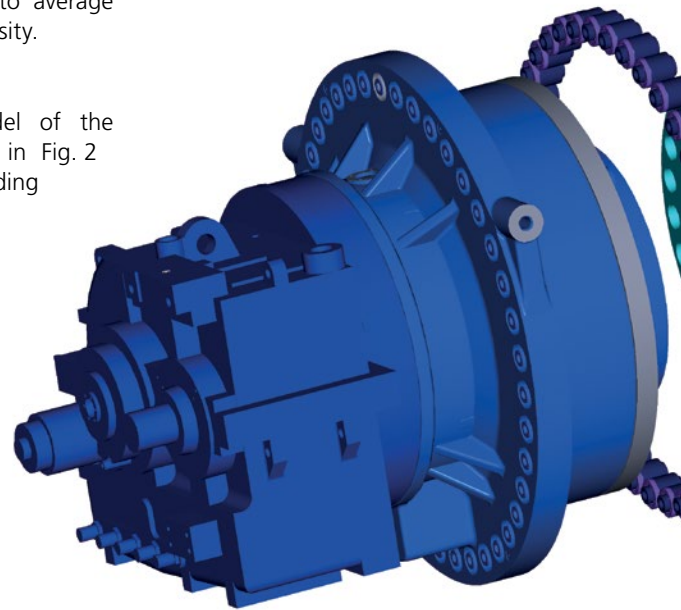


Fig. 1: 2 MW wind turbine including the drive train concept Larus Compact

The blades are connected with the hub of the main rotor by revolute joints for pitch control. The prescribed pitch motions are defined by user routines interacting with the controller described below.

The main components of the drive train are the hub, main shaft, gear ring, gearbox, brake and generator. The main shaft is connected to the nacelle by a revolute joint representing the moment bearing, while the coupling between main shaft and gear ring is described by a bushing element. The gearbox with the low-speed shaft (LSS) and the high-speed shaft (HSS) consists of two planetary gear stages and a spur wheel stage. The model includes torsional stiffness of the intermediate shafts as well as contact stiffness of meshing gears, implemented with user defined Force Elements. The gearbox is supported by means of bushing elements. Other elements of the drive train are the brake and generator consisting of the rotor and the elastically mounted stator. Friction loss is taken into account for the main bearing, the generator and the gear-

Turbine Simulation Model



LARUS COMPACT®

The clever drive train

box. The overall SIMPACK model has about 100 degrees of freedom.

PROGRAM INTERFACES

To apply aerodynamic loads, the SIMPACK interface for AeroDyn (Force Element 241) is used. AeroDyn is developed by the National Renewable Energy Laboratory (NREL) and is based on the blade element momentum theory (BEM). To apply the AeroDyn interface, specific markers on the multi-body model are defined. For the blades, aero-markers at each blade element, and aerodynamic blade element parameters, are specified. The aerodynamic influence of the tower is taken into account by aerodynamic tower data. To describe realistic wind conditions with turbulent, stochastically described windfields, AeroDyn is used in combination with TurbSim which is also from NREL.

To compare simulation results with measurements, the controller of the actual prototype turbine is built into the model. The controller generates desired values of pitch angular velocities and the generator torque

in dependence of measured values of the actual generator torque, angular speed of the LSS and the pitch angles (Fig. 3). The controller is time-discrete with a cycle time of 0.01s and is included in the model by another interface as a dynamic link library, DLL. The interface consists of user routines for controller initialization (Time Excitation), for controlling the pitch motions of the blades by rheonomic constraints (Joint), for application of the electric generator torque (Force Element), and for determination of input and output values for controller communication procedures (Force Element). Other external routines are used for global definitions and communication.

LOADCASE SIMULATIONS

Simulations of specific load case scenarios are essential in the design process and required by certification bodies. Besides nominal power production load cases, exceptions like gust loads, regular or emergency

stops, or failures in the controller loop have to be considered. The wind conditions at the actual location of the turbine are taken into account.

For validation of the 2 MW wind turbine model, load case scenarios of power production during nominal operation have been used. To reduce simulation time, only load cases with 9 to 11 percent of turbulence

“SIMPACK provides open-source solver scripts to conduct multiple simulations efficiently.”

are simulated. The average wind speed is selected according to the data provided by the capture matrix in a range of 4 to 16 m/s and a step size of 1 m/s. For reasons of reproducibility of the simulation results under the stochastic wind field conditions, each load case is simulated four times.

SIMPACK provides open-source solver scripts to conduct multiple simulations efficiently. Parameter variations, e.g., of the wind field, can be easily realized by input tables. With multi-core processors simultaneous simulation runs are possible.

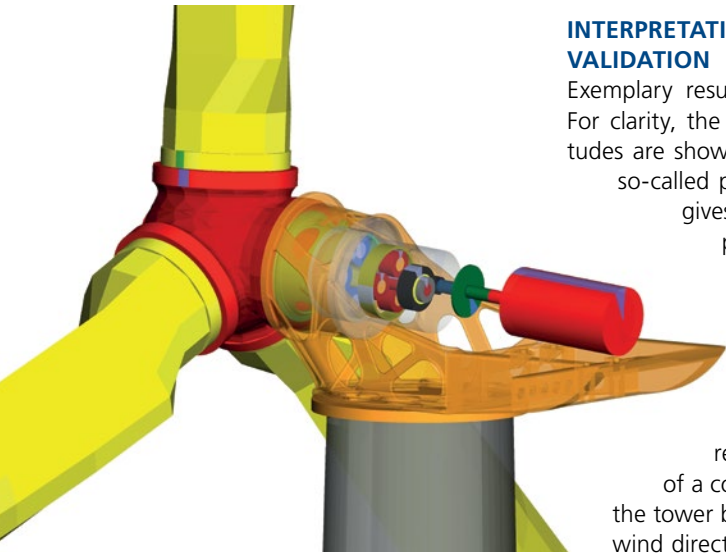


Fig. 2: Model of the 2MW wind turbine

Storage of the result files in specific subfolders supports post-processing of the results. The SIMPACK script has been modified in order to simulate the 2 MW wind turbine with the self-developed controller interface. The solver script helps to reduce the time requirement for the simulations and also avoid input errors.

INTERPRETATION, COMPARISON AND VALIDATION

Exemplary results are seen in Figs. 4 to 7. For clarity, the mean values of the magnitudes are shown in the diagrams only. The so-called power curve shown in Fig. 4 gives an estimation of the expected energy profit during operation in accordance to different wind conditions. The rotor speed and the pitch angle over the wind speed are shown in Figs. 5 and 6, respectively. As an example of a component load, Fig. 7 shows the tower base bending moment in the wind direction. The diagrams represent data of simulations (black points) and measurements (red points).

The magnitude of aerodynamic forces generating the driving torque at the rotor (Fig. 8) is based on the blade-tip velocity and the angle of attack. Both values are determined by the wind speed and rotor speed, the radius of the corresponding blade element and, in addition, by the pitch angle of the blade. To optimize power pro-

duction, the controller changes both pitch angle and generator torque.

In all diagrams, two ranges of wind speeds can be distinguished. In the partial load range (up to wind speeds of about 11 m/s), the controller keeps the pitch angle zero, while the rotor speed and the power increase. In the full-load range of wind speeds (above 11 m/s), the rotor speed reaches its nominal value of 15 rpm. The turbine then produces the rated power of 2050 kW. With further increasing wind speeds, the controller keeps both rotor speed and generator torque, and therefore the power, constant by means of increasing the pitch angle. Increasing the pitch angle reduces the force in the wind direction that in turn reduces the tower base bending moment in the thrust direction.

The plots in Figs. 4 and 5 illustrate good compliance between simulation results and measurements for power production and rotor speed in the partial and full load range. The simulated pitch angle in Fig. 6 shows a steeper increase in the full load range compared to the measurements. This deviation could be caused by a time delay in the pitch

“Comparisons between simulation and measurement results are in good compliance...”

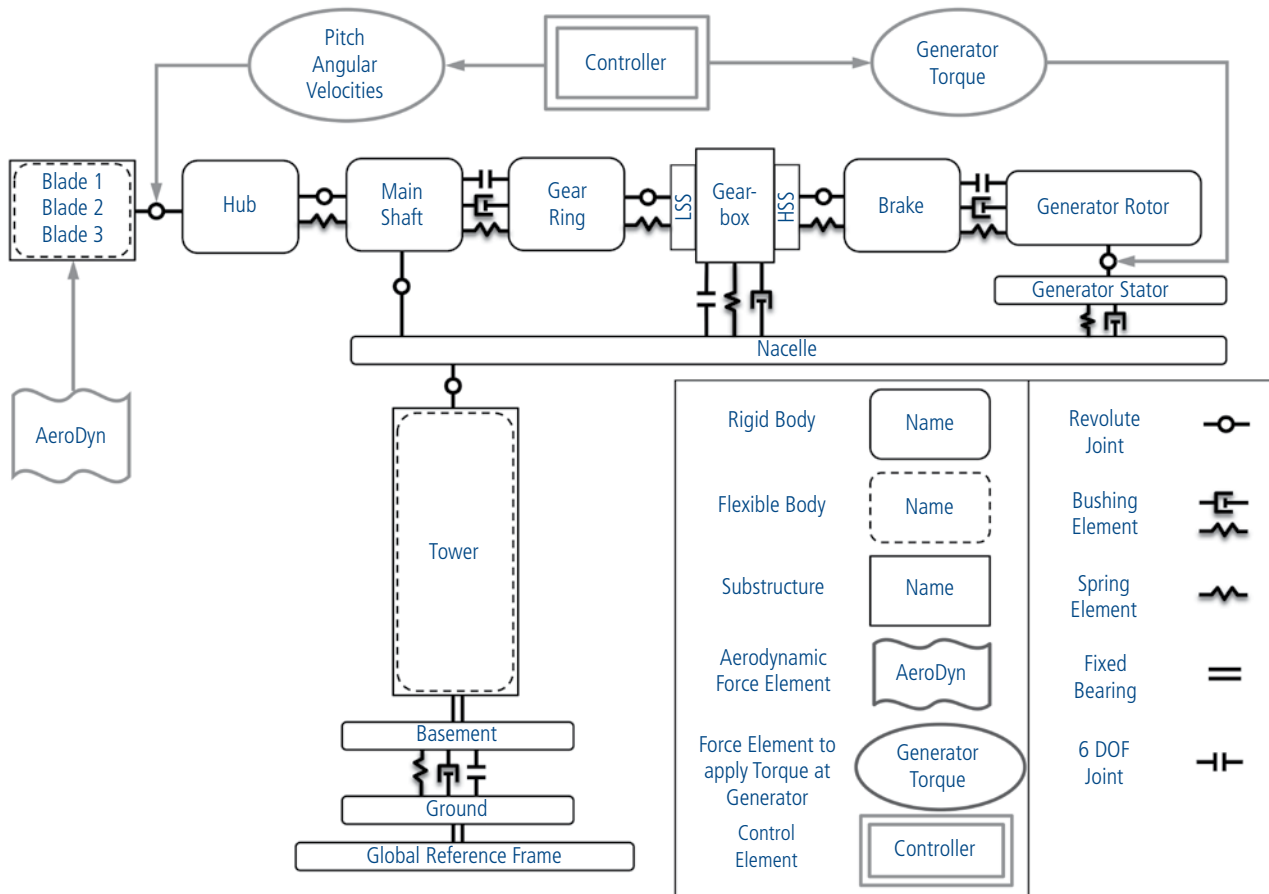


Fig. 3: Topology of the SIMPACK wind turbine model

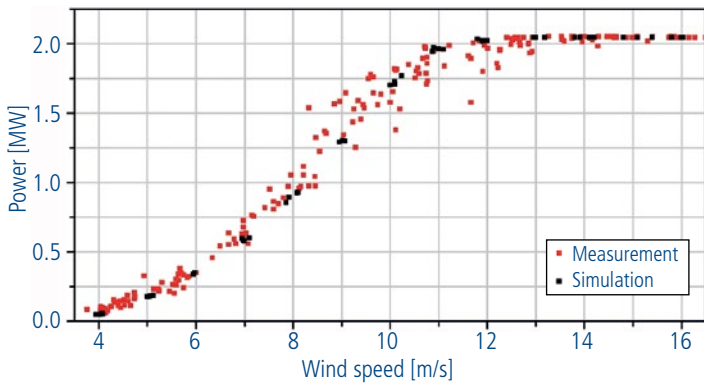


Fig. 4: Power curve; comparison between simulation and measurement

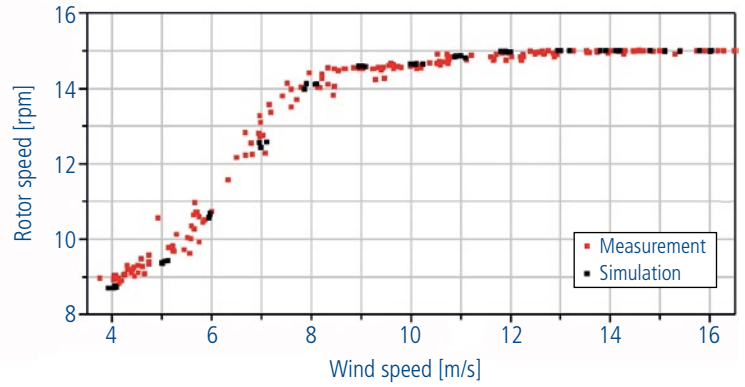


Fig. 5: Rotor speed; comparison between simulation and measurement

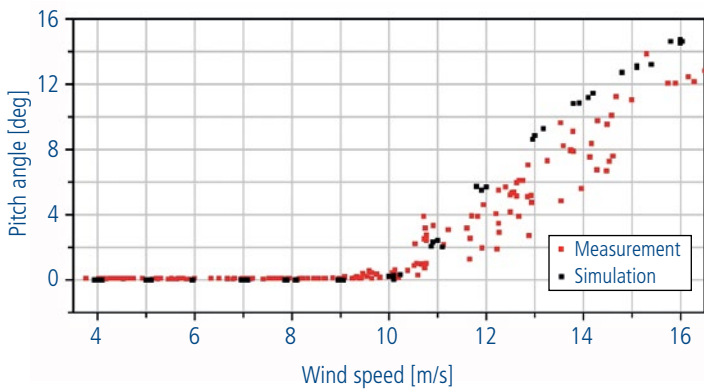


Fig. 6: Pitch angle; comparison between simulation and measurement

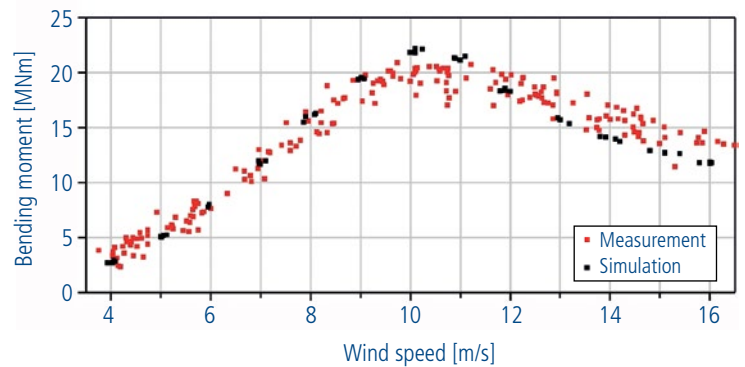


Fig. 7: Tower base bending moment in wind direction; comparison between simulation and measurement

control system of the prototype wind turbine. Until now, this effect has not been taken into account in the simulation. The simulated tower bending moment in the wind direction in Fig. 7 is beneath the measurements in the full load range due to its dependence on the pitch angle mentioned above.

CONCLUSION

A 2 MW wind turbine model has been developed and validated based on results of long-time measurements on a prototype wind turbine. Comparisons between simulation and measurement results are in good compliance as exemplarily shown for the power curve and the rotor speed. Minor deviations for specific results like pitch angle or tower base bending moment in the full load area need further model refinements. The validated SIMPACK model of the wind turbine will be used to further investigate dynamic interactions between the turbine and its drive train.

ACKNOWLEDGEMENT

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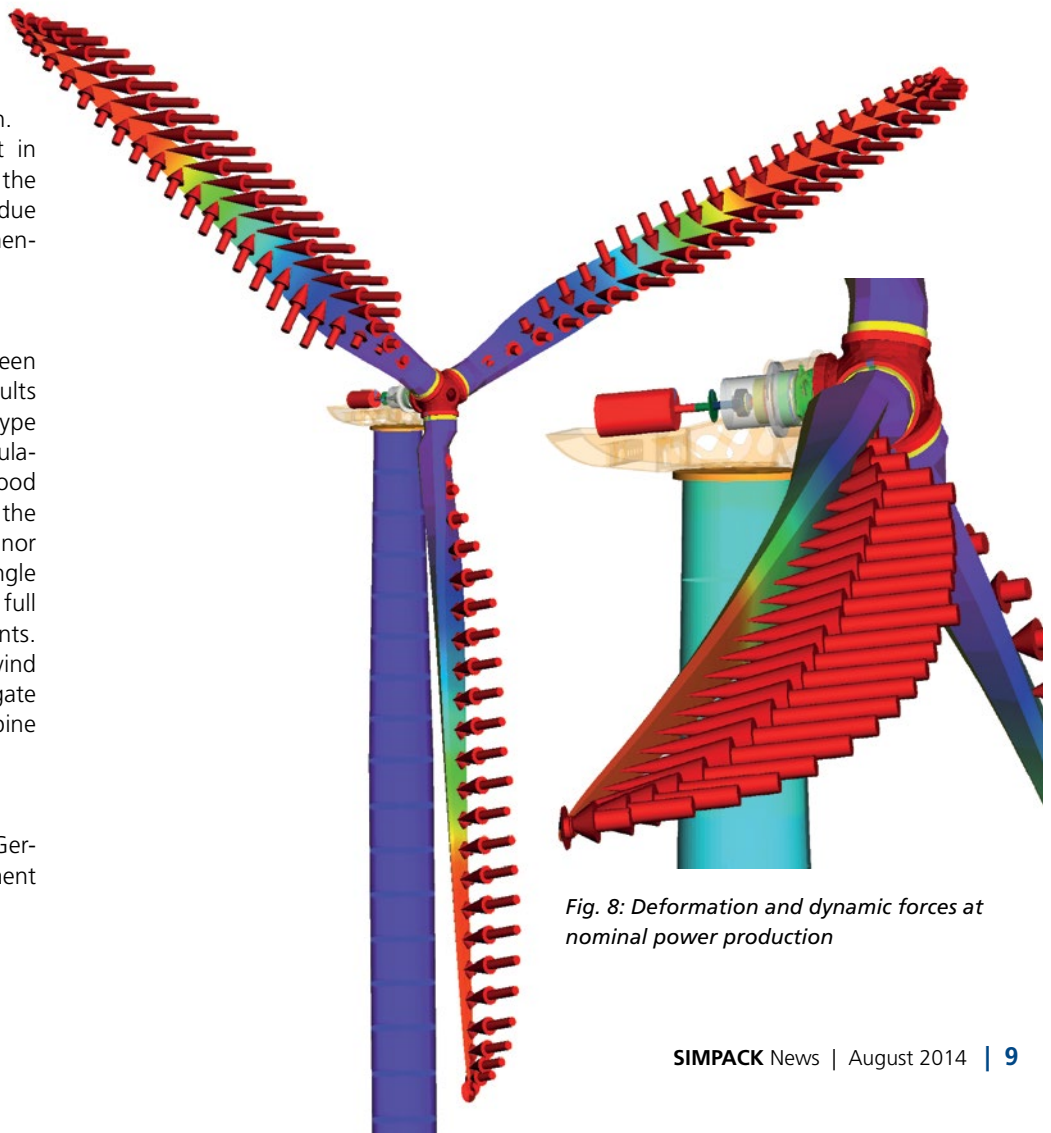


Fig. 8: Deformation and dynamic forces at nominal power production