A Measurement and Signal Processing Concept for the Dynamic Analysis of Operating Wind Turbines

János Zierath[1], Reik Bockhahn[1], Roman Rachholz[2], Sven-Erik Rosenow[1], Andreas Schulze[2], Johannes Luthe[2] and Christoph Woernle[2]

[1] *W2E Wind to Energy GmbH, Strandstrasse 96, D-18055 Rostock, {jzierath, rbockhahn, serosenow}@wind-to-energy.de*
[2] *Chair of Technical Dynamics, University of Rostock, Justus-von-Liebig-Weg 6, D-18059 Rostock, {roman.rachholz, andreas.schulze2, johannes.luthe, woernle}@uni-rostock.de*

The life time of a wind turbine is mainly influenced by its dynamics. In order to avoid resonances in the variable speed range of a wind turbine, resonant frequencies of the entire turbine including substructure resonant frequencies as well as harmonic excitations must be known accurately. Whereas the harmonic excitation frequencies are multiples of the rotational speed and well known, resonant frequencies have to be either calculated using a proper model or identified experimentally. A verification of calculated results by a measurement is the preferable approach. So the extensive knowledge and the deep understanding of the dynamics of a wind turbine allows the precise prediction of its behaviour.

This contribution presents modal testing of a 3 MW wind turbine on a 100 m tubular tower with a 120.6 m rotor developed by W2E Wind to Energy GmbH. The research is a part of the DynaWind project of the University of Rostock and W2E funded by the German Federal Ministry of Economic Affairs and Energy. This contribution mainly focuses on the application of operational modal analysis techniques to an industrial wind turbine. Specific problems are addressed, and hints for modal testing on wind turbines are given. Furthermore, an effective measurement setup including deformation measurement of rotor blades is proposed for identification of the modal parameters of a wind turbine. The measurement procedures evolved from the experience of different measurement campaigns on a 2 MW wind turbine presented in [1] and [2], while the knowledge on the dynamic behaviour of wind turbines have been gained from detailed multibody simulations [3].

A special measurement setup for modal testing has been proposed within this research work. The focus has been placed on the transfer of the measurement signals from the rotor to the nacelle and the type of sensors used for deformation measurement of the blades. For the modal testing of the blades it is necessary to use sensors which are able to measure low frequency ranges below 1 Hz on the one hand and a large measurement range of ± 2 g on the other hand. Based on this requirements Inertial Measurement Units (IMU) from Pepperl+Fuchs are used for dynamic analysis of the blades. IMUs have the advantage that translational acceleration and angular velocity can be measured at the same time representing a six-dimensional sensor.

Overall ten IMUs are placed on the wind turbine, eight in the blades, one in the nacelle and one in the tower. While one blade has been equipped with four IMUs at 5 m, 14 m, 22 m, and 28 m, the other two blades are equipped with two sensors at 5 m and 28 m. The communication between sensors in the blade and the IMC data acquisition system in the nacelle is realised by CAN bus and a slipring. In addition to the 60 signals provided by the IMUs seven steering signals from the Programmable Logic Controller (PLC) of the wind turbine are recorded by the IMC system. The signals comprise the pitch angle of the blades, the wind speed obtained by the anemometer on the nacelle, the electrical power, the rotor position, the angular velocities of rotor and generator, and finally the yaw angle.

A second data acquisition system from Bruel & Kjær has been positioned at the elevator platform. Eight piezoelectric accelerometers from PCB are positioned in the tower at tower heights of 16.5 m, 31.5 m, 49.5 m, and 70.5 m in two perpendicular directions. The elevator shaft has been used for positioning of the sensors with respect to the nacelle orientation. In addition three accelerometers are positioned at the rear of the main frame in the three independent translational directions. For synchronisation of the two data acquisition systems the rotor position is also recorded by Bruel & Kjær system. Finally two more accelerometers are positioned at the mainframe next to the yaw bearing in fore-aft and side-side direction also for synchronisation of both measurement data.

The ten IMUs and 13 accelerometers deliver 73 measurement signals. Considering the signals used for synchronisation 71 signals are usable for the dynamic analysis. In combination with the seven operating condition states of the wind turbine a dense measurement grid of the operating wind turbine is obtained. The overall measurement concept is shown in Fig. 1.

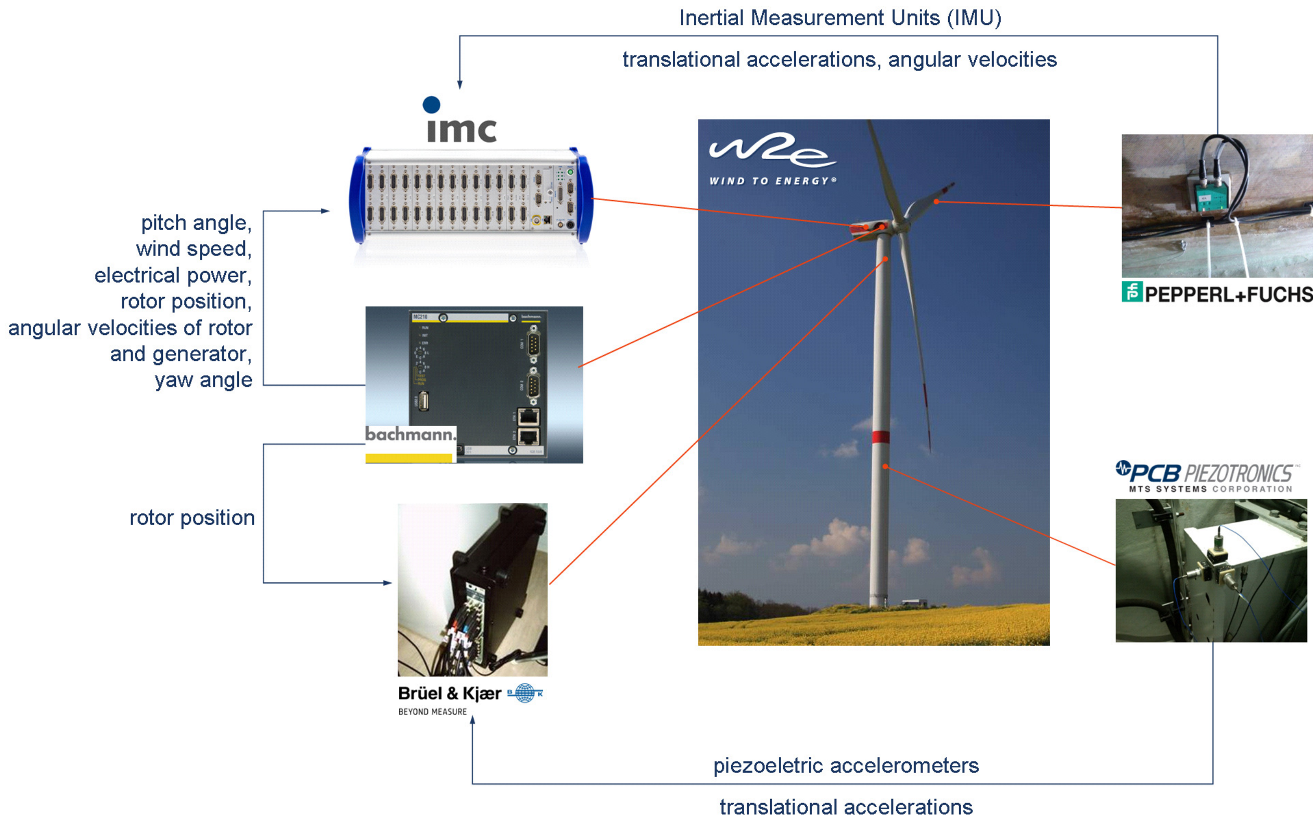

Fig. 1: Measurement Concept for the Dynamic Analysis of Operating Wind Turbines

The measurement data of of the two independent data acquisition systems are merged together and synchronised using FAMOS from IMC. Additionally a 0.7 Hz high pass filter is applied to the IMU data to reproduce the same dynamic behaviour as can be observed from the accelerometer data. Furthermore a 10 Hz low pass filter is applied to both data acquisition systems circumventing aliasing effects. Then the step size of both measurement data sets is synchronised. Furthermore some kinematic transformations are applied to the measurement data. So the tower measurement data have to be transformed with respect to the yaw angle. Furthermore kinematic calculations in MATLAB have been used for separating the deformation of the blades from their rigid body kinematics and differentiation of the angular velocities of the IMUs. The modes have been extracted by ARTEMIS Modal Pro 5.1.

The detailed experimental analysis of the industrial wind turbine is the basis for a more realistic multibody modelling of the flexible components e.g. by using substructuring methods, exact prediction of the loads acting on the wind turbine predicting its life time and advanced controller schemes based on observer methods.

References

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