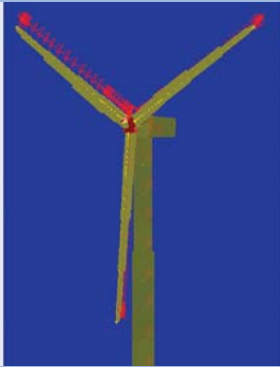


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Integration of an Aerodynamic Wind Turbine Module



MBS Model of the Entire Wind Turbine

In the last years wind turbines have increased dramatically in size so that their structural-dynamic behaviour is becoming progressively more important. Industrial simulation codes for wind-turbine-specific problems have some shortcomings in structure modelling, especially for drive trains. This leads to new approaches to wind turbine simulation. The Endowed Chair of Wind Energy at the Institute of Aircraft Design (University of Stuttgart) initiates the usage of SIMPACK for the simulation of wind turbine models. This requires some add-ons to SIMPACK. The most important of these consists of an aerodynamic module to consider rotor aerodynamics and turbulent wind field input.

STATE OF THE ART

The structural dynamics of wind turbines are nowadays simulated with special software codes, developed solely for this application. The majority of these simulation codes use a modal approach that considers only a rather limited number of natural modes. A few other tools apply finite element methods which are more powerful in principle but computationally inefficient due to the kinematical and material non-linearity of the system and the overall long calculation times. Recently it became obvious that all codes so far have deficits in modelling the drive train dynamics and its interaction with the other main components like blades, tower, etc. This leads to a poor significance of component coupling.

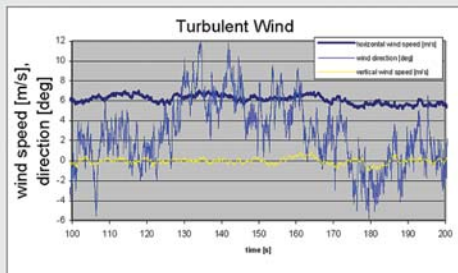
SIMPACK AS SIMULATION SOFTWARE FOR WIND TURBINE DYNAMICS

The multibody simulation software SIMPACK features an advanced simulation of structure dynamics. The multibody approach allows detailed modelling especially of the coupling of different components. This is why SIMPACK is already used for the simulation of wind turbine components such as the drive train, for example at the Technical University of Dresden

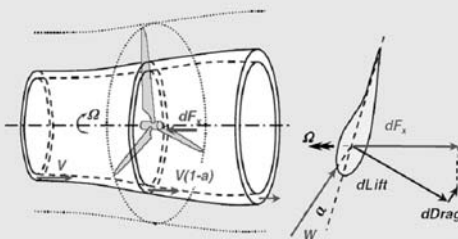
(Schlecht B. et al.; Assessment of Dynamic Loads in Multi-Megawatt-Drive-Trains by means of Multibody-System-Simulation; Int. Conf. on Gears 2005; Munich VDI-Report 1904, Vol. 1, 537-560). SIMPACK features a more exact simulation of structural dynamics than presently used standard software by employing non-linear beam models, coupling of degrees of freedom, etc. It offers a free choice of degrees of freedom, it has interfaces to implement further modules and it offers options to implement controllers. It also features general pre- and post-processing tools that can be used for wind turbine simulation. However, SIMPACK has to be extended to include further features of wind turbines, particularly rotor aerodynamics and wind field modelling. As standard simulation software codes for wind turbine simulation sufficiently consider rotor aerodynamics, they can be used to integrate into SIMPACK a state-of-the-art aerodynamic module. SIMPACK with its User Routines offers the possibility of implementing external modules.

AERODYNAMIC MODULE "AERODYN"

AeroDyn is a module for the simulation of wind turbine rotor aerodynamics developed by the US National Renewable Energy Laboratory (NREL). AeroDyn is already used in conjunction with other wind turbine simulation software. As all other industrial wind turbine rotor aerodynamics design tools, AeroDyn calculates aerodynamic loads using a combination of blade element and momentum theory, i.e. Blade-Element-Momentum-Theory (BEM). The global flow field is described by Froude's actuator disk theory originating from 1889 which was later adapted to wind turbine applications by Betz. In order to overcome the shortcomings of this rather crude method, several engineering rules are applied as corrections. AeroDyn considers most of these corrections, like Blade Tip Loss and Hub Loss. These corrections are necessary because of the 3-dimensional flow. The stream tube



Turbulent Wind Used in Simulation



Blade Element Momentum Theory Linking of the Global Rotor Flow Field (left) to the Local Blade Flow Field (right) by the Induction Force dF_x at an Annulus

approach cannot sufficiently describe larger misalignment of rotor axis and flow pattern since undisturbed wind and the wake are no longer parallel. This requires the Yawed Flow correction. A correction for conditions with high axial loading, the Turbulent Wake State is also implemented. The flow around wind turbines operating in the atmospheric boundary layer is inherently unsteady. Dynamic Inflow denotes all unsteady aerodynamics associated with the global rotor flow field. On the blade scale, the fluctuating external conditions result in hysteresis effects of the aerodynamic coefficients in the stall region (Dynamic Stall), depending on blade geometry and the frequency and amplitude of the flow variation. Another correction model takes the influence of the tower on the flow field into account. The most significant dynamic loading of wind turbines originates from operation in the turbulent atmospheric boundary layer. AeroDyn is able to read in 3-dimensional full-turbulent wind fields. A pre-processor called TurbSim, developed by NREL, can be used to generate such wind fields. Accordingly, AeroDyn with its pre-processors is a powerful module to simulate rotor aerodynamics.

INTERFACE AERODYN & SIMPACK

The interface that integrates AeroDyn into SIMPACK is written in a SIMPACK user routine. User routines provide a powerful capability for SIMPACK. They allow additional functionality to be imported into SIMPACK. Moreover, they are open for modelling features from other engineering disciplines to be included in a MBS model. It is possible to define user routines for different MBS elements such as force elements, joints, constraints, etc. The programming language can be either FORTRAN or C. The user routines can read in data during simulation via the SIMPACK Access Functions. Such Access Functions also allow the measurement of kinematical dependencies in the MBS model. Since AeroDyn calculates aerodynamic forces,

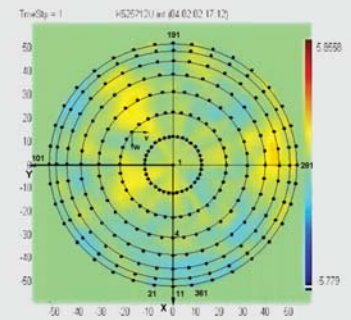
the interface is realised as a SIMPACK User Force. Aerodynamic forces depend on structural velocities of the blade elements. SIMPACK Access Functions are used to gain these velocities during simulation when the SIMPACK solver calls the interface code which conducts the aerodynamic calculation in AeroDyn. The interface code collects the relevant kinematic information of each blade element and transfers it to AeroDyn. By the time AeroDyn finishes the calculation, the interface affects the blade elements in the MBS model with the calculated forces.

SIMULATION EXAMPLE

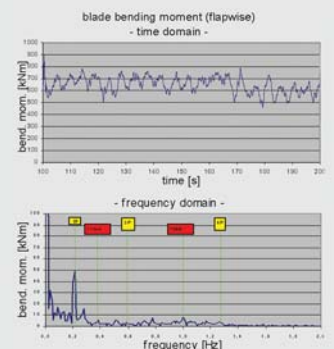
A typical wind turbine model with 1.5 MW power and 70 m rotor diameter was used to demonstrate the SIMPACK coupling and to analyse mass and aerodynamic imbalances in the presence of a turbulent wind field. It would have been possible to use a detailed structural model of the drive train, but the focus was on aero-elastic coupling. The interpretation was performed in both the time and frequency domains. It could be seen that the transient and stochastic effects of turbulent wind in particular have a major influence on the results.

CONCLUSION

The multibody approach of the simulation software package SIMPACK is a sophisticated tool to simulate the complex structural dynamics of modern wind turbines. SIMPACK's User Routines offer an easy way to implement external user-defined modules for specific problems like rotor aerodynamics, control, etc. These promising results encourage the further development of the wind turbine simulation capabilities of SIMPACK to serve the needs of the fast-growing energy industry.



3-dimensional Turbulent Wind Field Possibly Used by AeroDyn [Fig. GE Wind Energy]



Simulation Results: Structural Response on Turbulent Wind in Time and Frequency Domain



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