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Aeroelastic Simulation of Wind Turbines by Coupling a Free Vortex Wake Model with SIMPACK

The component most responsible for downtime is the gearbox. Furthermore, gearbox replacement and lubrication account for 38% of the parts cost for the entire turbine system. This calls for the implementation of new and advanced simulation techniques to be integrated into the gearbox design process so that they can meet their design life. There has been an incredible increase in the development of wind turbines during the last 50 years. The machines have developed from 34 m rotor diameter 100 KW machines to today's 120 m rotor diameter 6 MW machines. The speed of the scale-up has had a strong impact on the design process of these machines.

There is a need of more accurate simulation tools which fully consider the interaction of aerodynamics and structural dynamics. Different tools already exist, but they are usually based on the fast but simple Blade-Element-Momentum theory (BEM) and use very few modal degrees of freedom. The coupling of a free vortex wake module and a multi-body-simulation code is the next logical step to improve the accuracy of aeroelastic simulations.

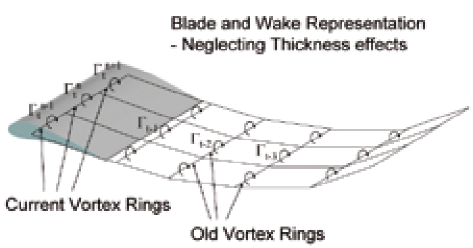

Fig. 1: Vortex Ring Distribution

Fig. 2: Wind Turbine at ECN

THE INVOLVED INSTITUTES

The project is coordinated by the Endowed Chair of Wind Energy (SWE) at the Universität Stuttgart, Germany, and the Energy Research Centre of the Netherlands (ECN). The SWE is Germany's first dedicated research chair in wind energy. The main research field of the SWE is the system characterisation of wind turbines. The main fields of expertise are structural dynamics, load monitoring, control and operation of onshore and offshore wind turbines and composite materials. Among other projects, the SWE is supporting INTEC in developing new SIMPACK Wind functionalities. ECN is the research centre of the Netherlands dealing with renewable energy sources and is located in the north of the Netherlands. ECN carries out research in the field of intelligent grids, energy in the built environment, solar energy, wind energy, biomass, hydrogen and clean fossil fuels. The ECN wind department will provide the Aerodynamic Wind turbine Simulation Module (AWSM), which is developed by Arne van Garrel [1] for the project.

THE AERODYNAMIC CODE

The idea is to develop a more realistic aerodynamic simulation code when compared to the standard BEM codes in use today. Special attention is directed to the wake physics, an important aspect of wind turbine load simulation. By these shortcomings in the modelling of e.g. yawed inflow, aerodynamic effects at the blade tip and root can be overcome. AWSM is based on the nonlinear lifting line vortex wake theory. A major assumption is that the lift, generated by a lifting surface, is modelled through vortex rings, which act at the quarter chord line of the blade. One vortex ring is applied to one blade stripe. The strength of each vortex ring is determined by the local onset velocity vector. The simulation is restricted to slender and planar or slightly curved blade geometries, which do not comprehend strong radial flow interactions. Viscosity effects are taken into account by the user assumed lift, drag and pitching moment coefficients and are a function of the local flow direction.

Incompressible flow is assumed since the velocities are much smaller than the speed of sound. Thickness effects are not modelled so that the flow field is only determined by the vortices and the wind speed. A sketch of the situation is displayed in Fig. 1. The geometry of the wake is determined by the time stepping method. At every time-step, the last calculated vortex rings flows off the trailing edge of the blade stripes. The wake sheds are connected at the corner points and are transported by the wind speed and the induced velocities of every vortex ring. This procedure enables the roll-up effect of the wake.

THE WIND TURBINE MODEL

The 1,5 MW reference wind turbine was taken from the National Research Energy Laboratory (NREL). Within SIMPACK, this model consists of the tower, the nacelle with the gearbox, high speed and low speed shaft, the generator and the rotor.

The three blades and the tower are modelled with the SIMPACK FEMBS module as finite beam elements. For the soft blades, 37 segments are used. The structural properties (i.e. the blade and the tower eigenfrequencies) are very close to the reference data. The largest differences appear in the 2nd eigenfrequency in fore-aft direction of the tower, but this can partly be traced back to the rough discretisation of the tower, only input data for four elements was available. The SIMPACK model is shown in Fig. 3. The aerodynamics are represented by the tilted and pitched rotor only. Thus, no tower effects are included so far. The lifting surfaces are separated into parts and segments and are constructed by the use of leading and trailing edge points. The structural motion is defined by the user given time series or, in case of the coupling with SIMPACK, by generating "snapshots" at each communication time.

THE COUPLING STRATEGY

The designed coupling [2] between both codes is completely independent of the input data (i.e. number of blades, number blade cross sections etc.). AWSM is coupled to SIMPACK by means of a force element User Routine. A serial coupling is implemented for the data transfers. All geometry information is then delivered to AWSM (i.e. rotation angle, pitch angle, deformations) and AWSM returns with the calculated local forces and pitching moment.

RUNNING A SIMULATION

Two initial conditions are important to perform successful simulations. The first condition is the equivalence of the modules in SIMPACK and AWSM because separate input files have to be created, followed by the demand of corresponding solver parameters for the communication.

In the consequence of developing the coupling, the generator model has two modes to dramatically reduce the simulation time: It can be used either as a driving motor or as an actual generator. Simulations are performed from idle and motor mode in order to help to accelerate the wind turbine rotor. At a certain rotation speed it is switched to the generator mode and operates normally. With this possibility, steady runup phases can be simulated and a simulation time of 15 s is enough to reach a static stationary rotation speed. In Fig. 4 an exemplary coupled simulation over 24 s is displayed. The picture shows the wake transport behind one rotor blade and the deformed blades are also visible. The wind is streaming from left to right. The wind turbine starts from hole-up and the generator is allowed to accelerate the system. The computational time depends on the solver parameters, especially the aerodynamic part, and can vary between five minutes and several hours for twenty seconds of the simulation time. Very precise parameters are used in the case of Fig. 4. Strong roll-up of the wake was allowed.

RESULTS AND PROSPECT

The coupling project was successful and aeroelastic simulations are possible with AWSM coupled to SIMPACK. However, different improvements could be implemented. For instance, the SIMPACK model could be extended with the pitch-controller and the SIMPACK rotor blade generator could be used to generate various blades.

Within AWSM, the most important issue is introducing a standard turbulence model for the simulation.

Fig. 3: SIMPACK Model

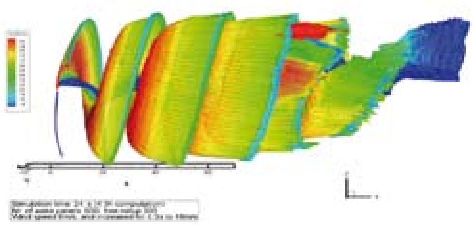

Fig. 4: : Results of Coupled Simulation

» LITERATURE:

[1] Garrel, A. v.: "Development of a wind turbine aerodynamics module", Report ECN-C--03-079, ECN 2003

[2] Kaufer, D.: "Coupling a Free Vortex Wake Model and a Multi-Body-Simulation Code for Aero-Elastic Simulation of Wind Turbines", Student Thesis, 12/2007, SWE/IAG -Universität Stuttgart

Further information:
www.uni-stuttgart.de/windenergie