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Aeroelastic Simulation of Wind Turbines Coupling SIMPACK with ADCoS

As the power output of wind turbines grows, the dimensions of the gearboxes that transmit power from the rotor to the generator have increased accordingly. The impact of dynamic gearbox behavior on other wind turbine components is significant, and is the subject of current investigations. To gain a deeper understanding of the influence gearboxes have on other components of a wind turbine, the multi-body simulation (MBS) software SIMPACK was coupled with the wind turbine load calculation tool ADCoS. ADCoS — a finite element tool specifically designed for wind turbine simulations — has proven its accuracy and efficiency over the past years. SIMPACK is a powerful tool for simulating gearboxes and drivetrains. This combination utilizes the specialties of both tools to investigate the dynamic influences of the drivetrain on other components of a wind turbine. This article lays out the realization of this coupling and its impact on the dynamic simulation of wind turbines.

ADCOS (AEROELASTIC AND DYNAMIC COMPUTATION OF STRUCTURES)

ADCoS is a simulation tool specifically designed for the aeroelastic simulation of wind turbines. It is used by Aero Dynamik Consult GmbH to predict loads on wind turbine components. Using this program, a wind turbine is modeled by either Bernoulli or Timoshenko beam elements — each beam element consists of two nodes with six degrees of freedom (Fig. 1). The calculation is based on the general equations of motion for oscillating systems. The equations of motion are solved by non-linear, implicit integration in the time domain. Centrifugal and acceleration stiffness are considered in the equations of motion. Stiffness and damping matrices are updated simultaneously at every time step. Nonlinear effects — like the flap-wise deformation of the rotor blades — are included in the simulation. ADCoS considers the torsional dynamics of the rotor blades when calculating aerodynamic loads. This leads to very accurate results for displacements and bending moments. Due to use of a general finite element method in ADCoS, arbitrary support structures and tower designs can be modeled and analyzed. Both non-turbulent and turbulent wind fields can be used to perform calculations according to IEC [1], GL [3] and DIBT [2] standards. The component of interest of this investigation, the drivetrain, is modeled by a simple double oscillator.

"The best way to utilize the benefits of both SIMPACK and ADCoS is co-simulation."

Fig 1: ADCoS wind turbine model

INTERFACE BETWEEN SIMPACK AND ADCOS

The best way to utilize the benefits of both SIMPACK and ADCoS is co-simulation. The interface is realized via a standard SIMPACK interface using a Force Element. Windows sockets — a library of functions for the exchange of data in a network — are applied for the data exchange. The Windows sockets function library can communicate via network, allowing users to run ADCoS and SIMPACK on different computers within the same network.

For the simulation, the wind turbine is modeled in ADCoS, and the detailed drivetrain in SIMPACK. The parameters exchanged in this coupled simulation are the aerodynamic torque at the hub, the rotational speed of the rotor, the generator torque and the rotational speed of the generator. The aerodynamic torque of the rotor is determined in ADCoS and submitted to the SIMPACK drivetrain model, where it is applied at the main shaft.

The torque-speed curve of the generator is considered in the drivetrain model by Control Element 146. The rotational speed of the rotor, the generator torque, and the rotational speed of the generator are determined via time integration in the SIMPACK drivetrain model and sent back to ADCoS. With this information, ADCoS continues its calculation for the current time step. All

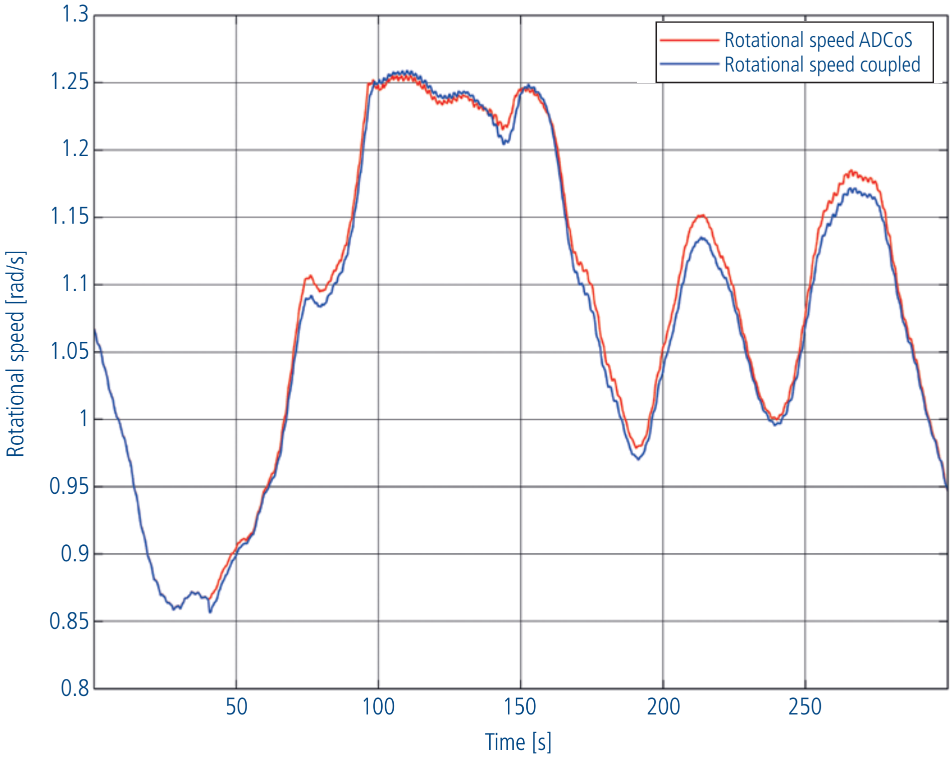

Fig 2: Comparison of rotor speed in both a coupled and a pure ADCoS simulation

gear contacts of the drivetrain model are modeled using the very detailed and realistic force element FE 225. The gearbox is a typical design for a 5 MW wind turbine with two planetary gear stages and one parallel gear stage.

LOAD CASES

Standard load simulations have been performed to validate the correct implementation of the coupling. These tests also investigate how the detailed modeling of the drivetrain influences the results of load simulations compared to pure ADCoS simulations. Three different design load cases (DLC) are carried out according to IEC 61400 [1]: DLC 1.1 Power Production, and emergency shutdown with (DLC 2.2) and without (DLC 5.1) occurrence of loss of electrical network connection. The evaluation of the results of an emergency shutdown is limited to the scenario with the additional occurrence of a grid loss.

RESULTS OF LOAD CALCULATIONS

To validate the correct implementation of the coupling, the rotational speed of the rotor and the generator torque are compared between a coupled simulation and a pure ADCoS simulation. Fig. 2 depicts the rotational speed of the rotor for DLC 1.1 (power production) of the turbine facing a turbulent wind field (mean wind speed of 8 m/s). The similarity of the two curves shows that the coupling was implemented correctly. Precise observation of the two curves reveals larger fluctuations in the coupled simulation. These fluctuations are particularly distinctive when the rotor speed reaches the rated rotor speed of the wind turbine. The same effects are seen and are even more significant for the generator torque of a coupled and a pure ADCoS simulation (Fig. 3). The fluctuations in the range of the rated rotor speed originate from resonance effects in the drivetrain and will be subjected to a more detailed investigation.

An even more interesting load case concerning the dynamic behavior of the drivetrain is the emergency shutdown of the wind turbine since excitations of a wide range of frequencies arise from this situation. A significant effect of the detailed modeling of the drive train can be observed in Fig. 5. Here, an emergency shutdown with a loss of network connection occurs at 80 s simulation time. The wind turbine is exposed to a homogeneous wind field of 8 m/s in this simulation. Due to the grid loss, the rotor speed rises in the coupled and the pure ADCoS simulation immediately after the emergency shutdown. Following this peak, oscillations with a constant frequency occur for the rotor speed of the coupled simulation. Oscillations with this frequency are apparent in the generator speed and the aerodynamic torque of the rotor as well. The reason for this effect is the modeling of the drivetrain in this investigation. The generator is modeled solely by its torque-speed curve. This neglect of damping of the generator leads to a direct influence on any

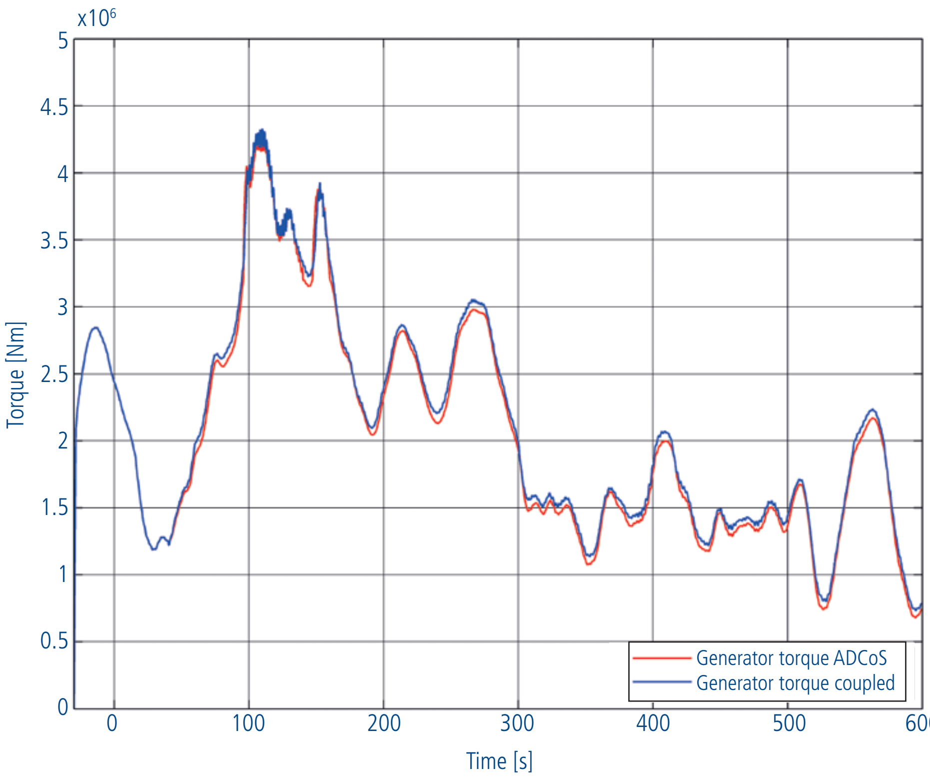

Fig 3: Comparison of generator torque of a coupled and a pure ADCoS simulation

change in the aerodynamic torque on the rotor and generator speed. For future applications of the coupling, damping effects of the generator will have to be considered in the model of the generator to investigate these oscillations in a more realistic manner.

RESONANCE ANALYSIS OF THE DRIVETRAIN

In order to gain a deeper understanding of how the dynamics of the drivetrain influence other components of a wind turbine, the drivetrain in this investigation is specially modeled to have an eigenfrequency that can be excited in the range of the rated rotor speed. For the drivetrain used in this analysis, the rotational mode of the planets of the second gear stage is excited in the region of rated rotor speed. Characteristic of this mode are an identical motion of all planets relative to their bearings and a pure rotation of the planet carrier, the ring wheel and the sun. The inertia of the rotor is the reason why only a very weak influence of this resonance of the drive train can be observed in the rotor speed and the rotational speed of the sun of the first planetary stage. The effect of the resonance is clearly recognizable in the rotational speed of the sun of the second planetary stage and the generator speed. The reason for the significance of this effect is the neglect of the damping of generator enabling the generator shaft to oscillate undamped. Since there is no significant impact of this resonance on the rotor speed, the influence on other components of the wind turbine is negligible.

CONCLUSION

The development of a coupling between SIMPACK and ADCoS reveals that a co-simulation of these programs is ideal for investigating the interactions of the drive train with other components of a wind turbine. The effects of a more detailed drivetrain model that utilizes the features of SIMPACK are clearly noticeable in the aeroelastic simulation of a wind turbine. For future applications of this coupling, more parameters should be exchanged between the two processes. For a more accurate reproduction of real dynamic wind turbine behavior, the forces and moments at the gearbox support must be submitted from SIMPACK to ADCoS. This will enable the model to transfer these loads to the tower via the bedplate. To capture the influences of the drivetrain and other components more accurately, the motions and accelerations of the nacelle will have to be transferred to the drivetrain model. This will influence the forces and torques acting on the drivetrain. Finally, the damping of the generator needs to be considered in the drivetrain modeling in SIMPACK in order to obtain more realistic results.

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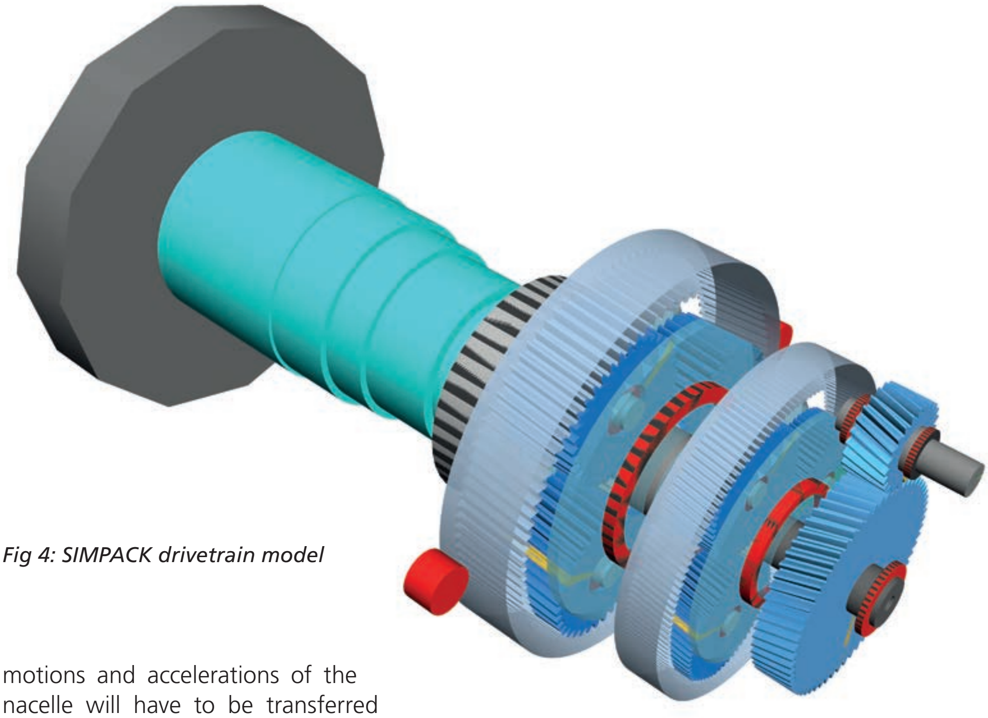

Fig 4: SIMPACK drivetrain model

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[1] IEC 61400-1 Wind turbines — Part 1: Design requirements, Third Edition, 2005-08

[2] Schriften des Deutschen Instituts für Bautechnik (DIBT). Richtlinie für Windenergieanlagen, 2004

[3] Germanischer Lloyd. Guideline for the Certification of Wind Turbines, 2010.

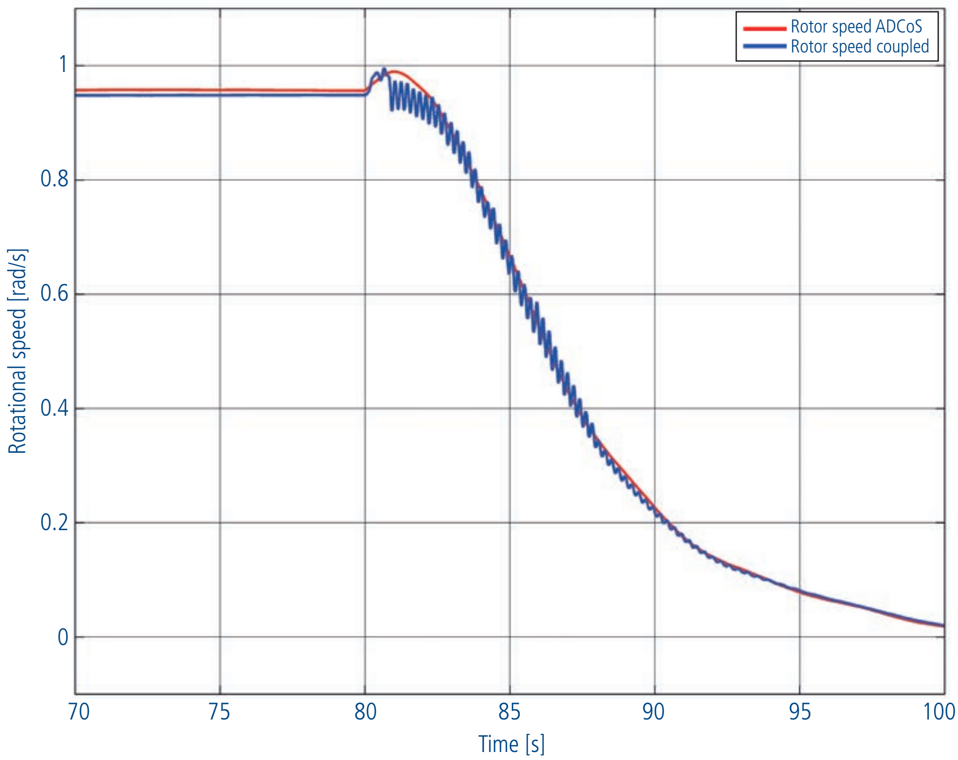

Fig 5: Comparison of rotor speed of a coupled and a pure ADCoS simulation of an emergency shutdown with loss of electrical network connection