Wind Turbine Drivetrain Design using Multi-Body Simulation Analyses

The design of Wind Turbine drivetrains is based on load assumptions which are generated by global turbine simulations. In industry, these global loads are supplemented by expert assumptions and are extrapolated by static procedures to generate local load assumptions for the design of machinery elements, e.g. gears, bearings, shafts and splines. Using multi-body simulation (MBS), this procedure can be improved with respect to confidence of load assumptions for strength verifications.

SCOPE OF ASSESSMENT

The drivetrain of global turbine models is described with parameters such as flexible body properties of rotor blades, rigid body properties of rotor hub, and generator and stiffness characteristics of the complete drivetrain. As a first step, these global drivetrain characteristics need to be compared to the behavior of a detailed drivetrain consisting of several sub-models, e.g. for gearbox, torque support, generator coupling and generator. For this purpose, calculation of global drivetrain stiffness is of interest. This is performed not only to confirm the drivetrain loads from global load assumptions but also for blade, tower and foundation loads. This is analogous to the comparison of isolated component Eigenfrequencies of the model and real components which is done for blades by means of measurements. Therefore, a detailed drivetrain model can be used. After validation of the drivetrain parameters of the global drivetrain model, a resonance analysis of the detailed drivetrain is needed to justify the procedure for static load extrapolation [1, 2].

MODEL SETUP

To confirm the assumptions of load simulations of drivetrain components, the setup and analysis of the detailed drivetrain is necessary. For these models, SIMPACK provides a variety of elements, e.g. flexible bodies, non-linear stiffness functions and gear force elements which provide the needed sectional loads in the drivetrain. During the modeling process, the need for an optimized topology was a major factor in the development of a drivetrain model. Optimization was supported by the use of visualized topology of every substructure employed in the process. Difficulties originating from different modeling approaches were spotted at an early stage and further action was taken to minimize the impact of certain modeling decisions.

SIMULATIONS IN TIME AND FREQUENCY DOMAIN

Simulations in time and frequency domain are two examination methods for the analysis of dynamic drivetrain behavior. In general, the first analyses are carried out in the frequency domain to find the Eigenfrequencies of the drivetrain structure. Depending on the non-linearities of the model, these Eigenfrequencies are not constant due to load depending stiffnesses, e.g. bearings. These Eigenfrequencies can readily be compared to global turbine modes from global load simulations or global load measurements. By doing this, the confidence level of the simulation model can be improved. As a next step, the dynamic behavior of the drivetrain

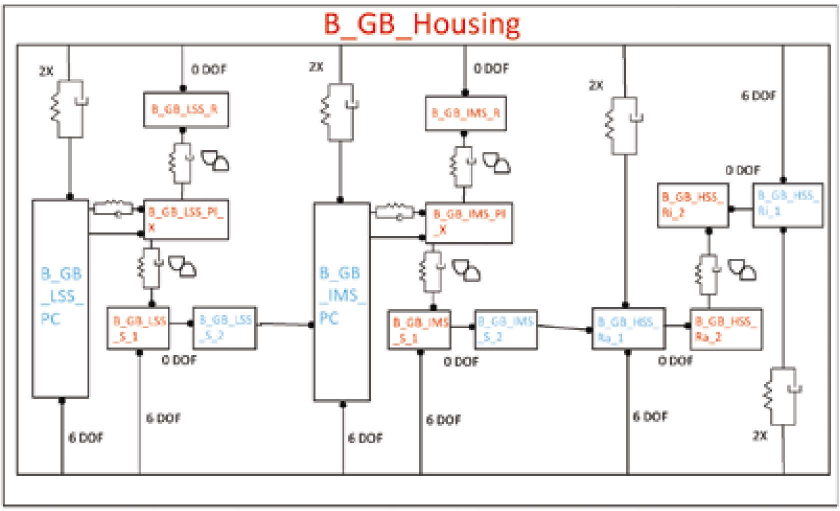

Fig. 1: Topology-map of a wind turbine model

is investigated by means of simulation runs in the time domain. Depending on the complexity of the model, it is possible to review the loads acting in different sections of the drivetrain, e.g. gears, bearings, splines and shafts.

> *“...design flaws can be avoided in the early design phase.”*

SPECIFICATION DRIVEN DESIGN

The increasing complexity in simulation models poses the threat of getting lost within the model. Abstract representations are the key to solving this issue: on the one hand, helping the modeler to stay on track and on the other hand, giving a basis for discussion and clarity.

GEARS

For modeling of involute gear contacts, SIMPACK offers a dedicated force element (FE 225) which enables the implementation of the gear mesh non-linearities in terms of fluctuating stiffness and backlash. The preciseness of the gear contact can be improved by introducing sliced gear contacts which is automatically done in the force element. Additionally, an iterative change of the parameterization of the FE 225 (tip relief factor, gear blank factor and teeth stiffness ratio) allows adjustment of the stiffness behavior to measured or calculated gear stiffness characteristics.

BEARINGS

In WT drivetrains, mostly antifriction bearings are used. These bearings feature a non-linear stiffness characteristic including operational clearance. For modeling of this stiffness behavior, SIMPACK provides the force element FE 043 which allows one to use either constant stiffness values or input functions. In most bearing applications, the stiffness behavior is dependent on the loading conditions of the bearing, i.e. the stiffness behavior depends on the interaction of external bearing loads. This bearing behavior can be modeled by means of stiffness matrices (FE 041). Both approaches have a rather big impact on simulation results [3]. Therefore, it is important to adjust the choice of elements according to the target goal of the simulation.

SHAFTS

State-of-the-art representation of shafts is achieved by using flexible bodies.
Depending on the geometry of the parts, the stiffness and mass properties can be included in the model by using a model representation of either beam elements (SIMBEAM) or the full structure (FEMBS).

STRUCTURAL COMPONENTS

The drivetrain of a wind turbine consists not only of rotating structural components like planet carriers but also non-rotating components like the gearbox housing including torque arm, main bearing housings and mainframe. The elastic behavior and the mass properties are modeled by flexible bodies using the modal representation. The rotorblades and tower are also modeled as flexible bodies.

SPLINES

The drivetrain of geared Wind Turbines uses spline connections in most cases. Once the stiffness characteristics are known, the elastic behavior of these machinery elements can be easily modeled by means of force elements, e.g. FE 043.

GLOBAL DRIVETRAIN STIFFNESS

During the design phases of wind turbines, different abstraction levels are needed to answer questions properly. In global models, drivetrain stiffness is represented by a single spring element, the properties of which need to be confirmed. Once the machinery components are designed and the drivetrain model set up, the global drivetrain stiffness can be determined.

DRIVETRAIN RESONANCE ANALYSIS

State-of-the-art design of drivetrain components is based on static approaches in terms of loads and deflections. By means of MBS, it is possible to confirm these assumptions. Additionally, the simulations can be used to define more boundary conditions for the different drivetrain components, e.g. generator coupling and generator bearings, thus, improving the quality of the component verifications. By analyzing the dynamic properties of the drivetrain, it is also possible to investigate the interaction of the components and to identify the design drivers with regard to discovered dynamic effects.

CONCLUSION

The design of WT drivetrains can be supported with the results of MBS. In this way, design flaws can be avoided in the early design phase. The importance of this is increased with the amount of risk, e.g. on offshore projects.

REFERENCES

[1] Germanischer Lloyd, Guideline for the Certification of Wind Turbines, Edition 2010

[2] International Electrical Commission, Design Requirements for Wind Turbine Gearboxes, IEC61400-4 Ed.1, CDV:2010-12

[3] Heavy Drive Train Conference ATK2011, ADTS II – Gemeinschaftliche Simulation einer Windenergieanlage – Industrieller Ansatz, Modellverbesserung durch Prozessoptimierung, Schaeffler Technologies GmbH & Co. KG

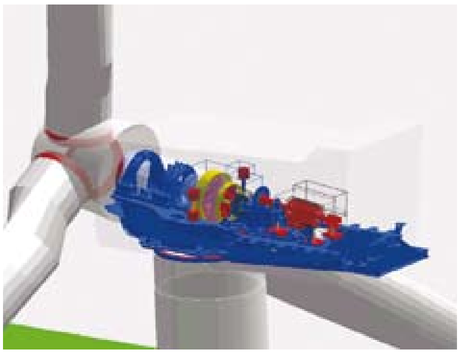

Fig. 2: Drivetrain model