A simulation platform for complex, large-scale modular energy systems

Tobias Meyer, Niklas Requate, Marcus Wiens, Juliane Burfeind
Fraunhofer-Institute for Wind Energy Systems, Am Luneort 100, 27572 Bremerhaven
tobias.meyer@iwes.fraunhofer.de

The need for a new simulation platform

The entire development chain in wind energy is highly dependent on models for all levels of the entire system. This starts with the site conditions and ends with the feed-in of energy into the grid. However, with a more holistic approach to wind energy system development, the scope of the system model is increasing as well. This is the case for most current research topics, such as systems engineering, wind farm control, hydrogen integration, integrated energy systems. In all of these fields, the wind turbine itself becomes just one component in a larger system, which is composed of multiple turbines, additional components such as electrolyzers and complex interconnecting models that represent the behavior of the natural environment.

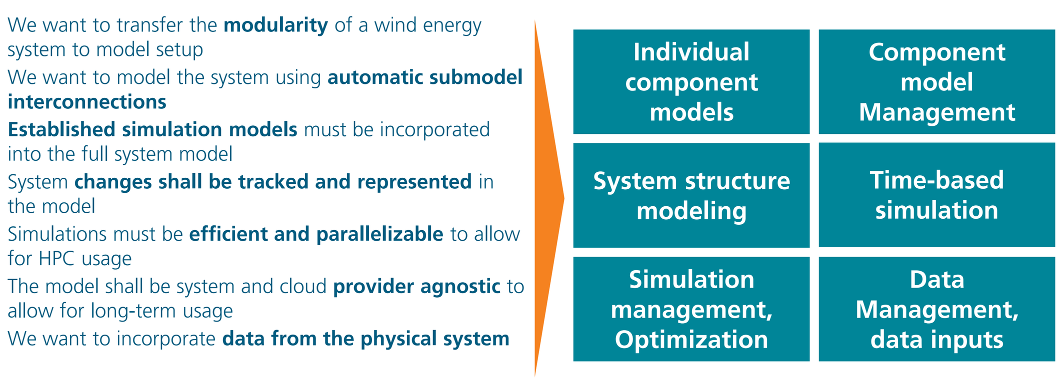


Fig. 1: Demands and required aspects of simulation platform

However, the wider the system boundary is defined and the more complex the system becomes, the more difficult a full system simulation and optimization becomes.
We aim at supporting the development of energy systems with a dedicated simulation platform for modular systems. In this, each component is represented by an individual component model.

Concept of Simulation Platform

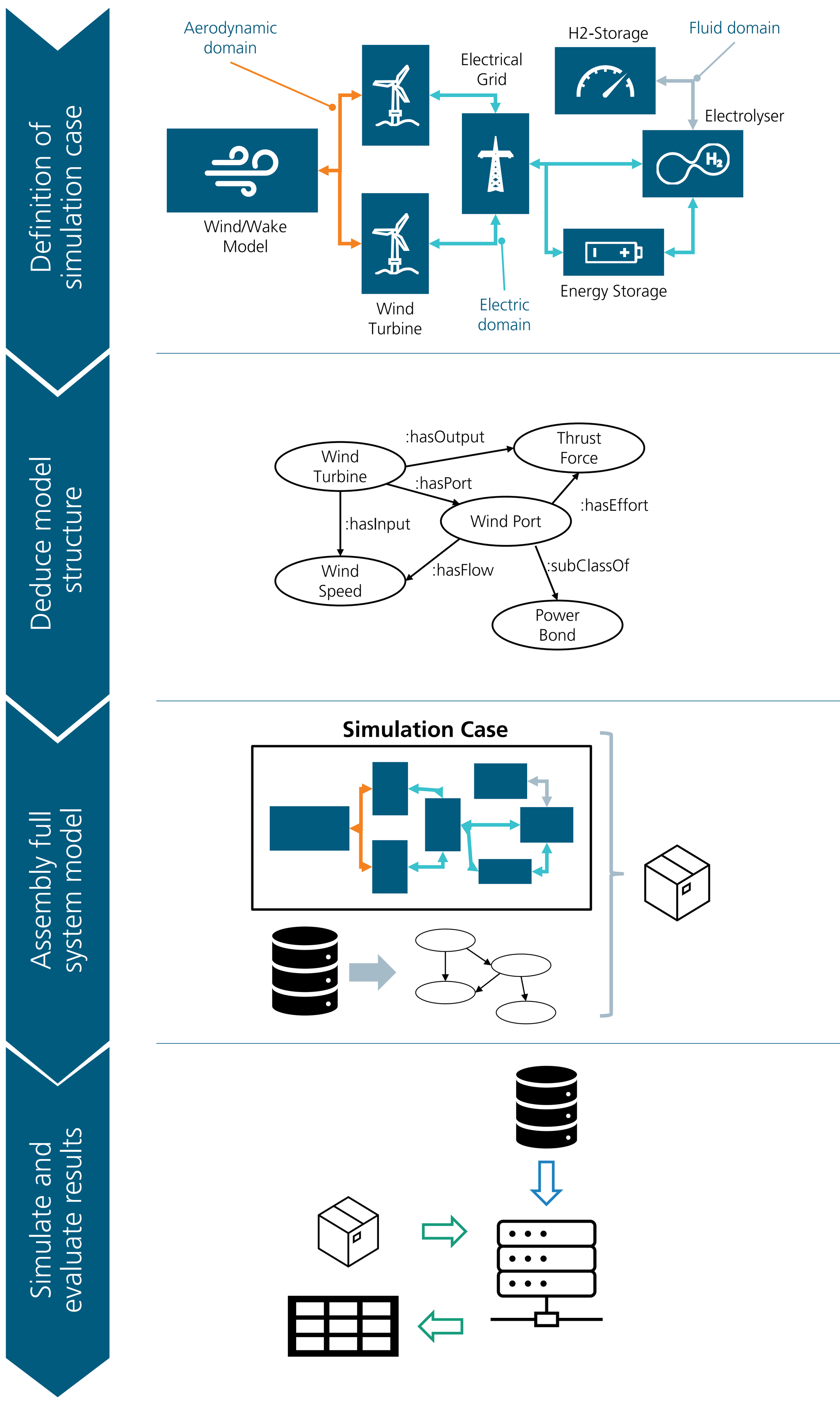
We propose a simulation platform that is comprised of three elements:

1. Database of component models
   These exist for all major aspects of a wind energy system but are developed independently and are highly specialized for solving a specific problem. The platform aims at unification of these models such that they can interact directly, without requiring an in-depth adaptation of each individual component model.
2. Automatic assembly into full system model
   User input should be limited to modeling the component interactions, not their specific model signal connections. The user sets up a system description, individual models must be linked automatically into a full system model.
3. Automatic system simulation and analysis
   The process of running simulations and working with simulation data should be as streamlined as possible, with as little specific input for individual simulation processes as possible. This requires automatic model configuration, e.g., the parameterization of the model, simulation execution, and evaluation of simulation results, individually for each simulation or combined for a full set of simulations.

Co-simulation based on the open functional mock-up interface (FMI/FMU) is a good means for including existing component models into a larger model. We wrapped individual IWES component models such as MoWiT (Modelica for Wind Turbines) or foxes (Farm Optimization and eXtended yield Evaluation Software) into FMI; either using existing compilation process from the respective host software (MoWiT in Dymola) or manually with dedicated libraries (foxes with PythonFMU).

Basic workflow for model setup and system simulation

The whole workflow builds on a system model which describes not the coupling of the individual component models on signal level directly, but the interaction of components on system level.



The process from this system structure to the interconnection between components models and onwards to a simulation is shown in Fig. 2.

In a first step, the simulation case is defined by the user. The basic mindset is to define the energy flows, e.g., between wind, turbine, and grid. This is simplified with standardized connectors, which are pre-defined based on Power Bonds. In these, power is split into effort (a potential) and flow (an energy carrier), which have opposite causality. This way, a physically meaningful coupling is ensured. The model itself is composed of component models, which are provided in a library.

Next, an automatic evaluation of the system description finds interconnections between components and maps them to individual signals between component models. This makes use of the standardized connectors and their definitions. If new connections are required, the first step is to provide appropriate connectors, then to implement them in the component models as required.

The full system model is the assembled from the simulation case, specifications of component models, their connector information and the corresponding signal connections. The simulation model is parameterized and wrapped into a self-contained package, which can be run without requiring additional inputs.

The simulation case package is transmitted to a server, which adds the component models from the database and starts the simulation. This setup leads to a highly scalable solution, where each simulation can be run separately, and many simulations can be executed quickly and well organized.
Simulation results are returned to the user, where additional evaluations are possible

Fig. 2: Workflow from model setup to simulation and evaluation of results

Use-case: Operational optimization of wind turbine in wind farm

The goal of an operational optimization is to maximize revenue, or a similar objective such as net present value, over a long period of operation, e.g., 20 years lifetime. This makes best use of existing components, so the operational regime has to stay within the bounds that component design sets for load bearing capacity.
The approach used is that of a model-based optimization for all operating conditions over the full lifetime of the system. This requires the use of a model that covers all relevant aspects, see Fig. 3. The optimization variables are included as operating strategy, which is a direct input into the simulation.
The whole process is shown in Fig. 4. The wind distribution is subdivided into individual operational states, and for each state the loads, the damage increment and the resulting energy and revenue is computed. Optimization then adapts the power setpoint for each operational state such that the objective is maximized. This results in a state-dependent power setpoint and damage increment. Fig. 4 shows clearly that some inflow angles lead to higher loads, damage increments, and power is reduced here preferably. In these inflow angles, other turbine's wake impacts the turbine under study.
In this example, only the combination of multiple models from different domains allows for full optimization. It results in a large increase of lifetime and revenue over simpler operating strategies, that are not based on as detailed models.

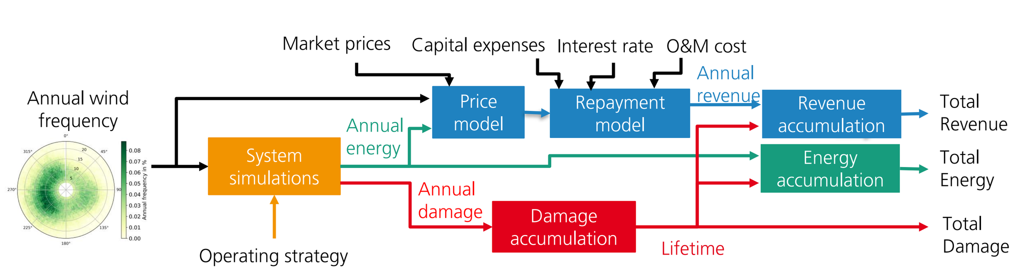


Fig. 3: Simulation model from wind frequency to accumulated revenue, energy and damage

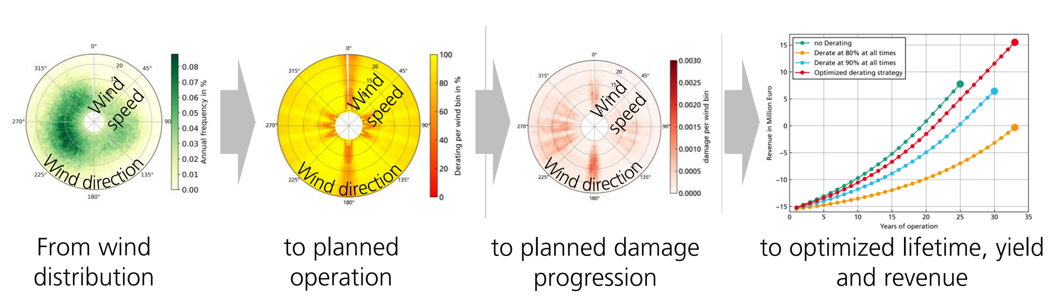


Fig. 4: State-based operational optimization