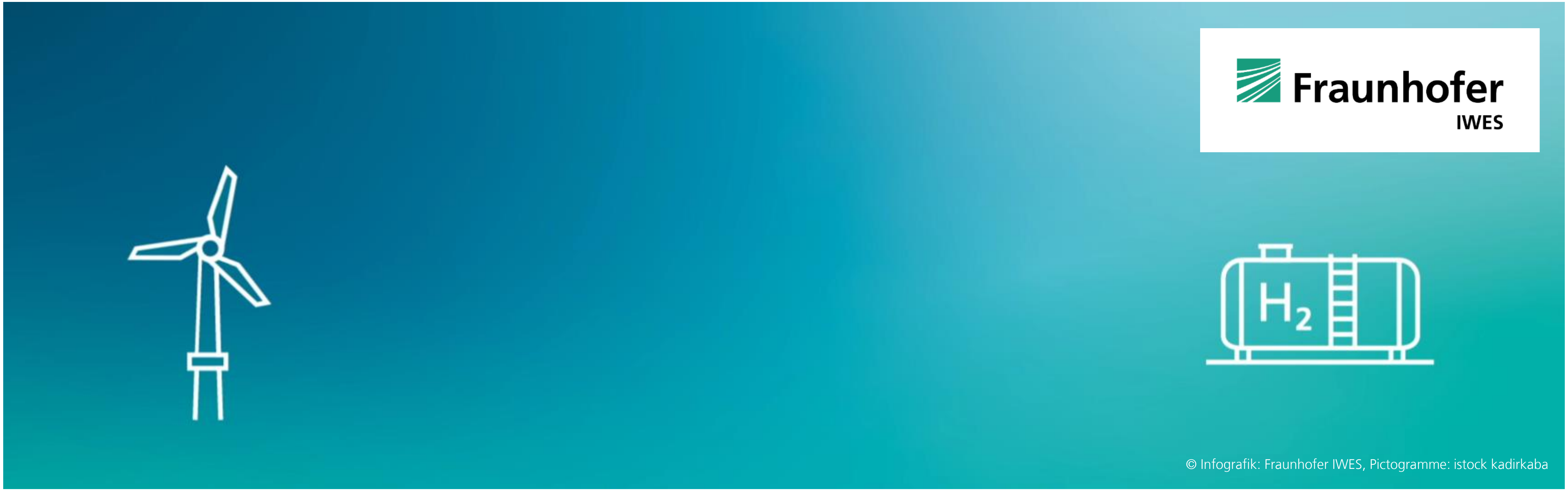


16.01.2025 / DeepWind

Large scale simulation models of combined wind-electrolyser plant for virtual testing based on FMUs

Marcus Wiens

Modelling of Hybrid Power Plants

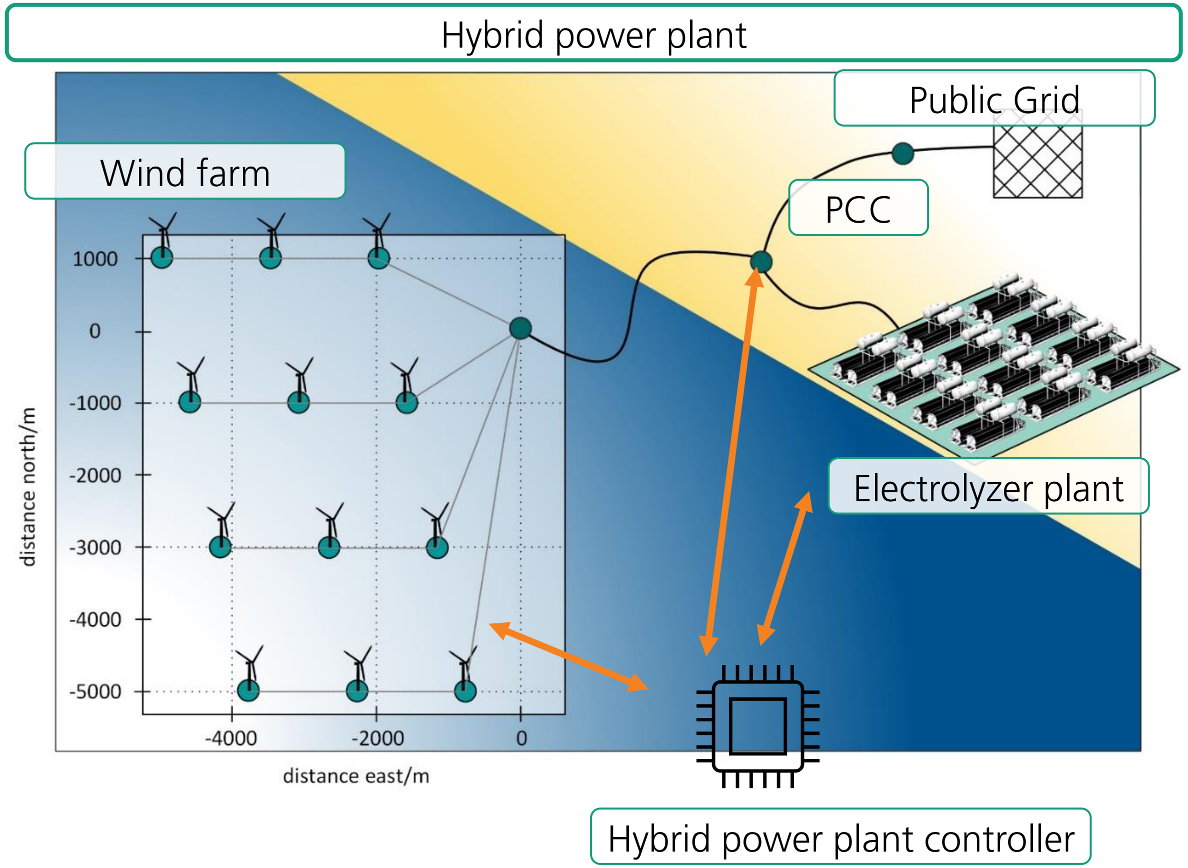
Hybrid power plants are attractive for operators

- saving costs and increasing flexibility of operation
- decoupling from regular grid operation

New challenges arise:

- Different domains are coupled
- Degrees of freedom for controlling the plant is high
- Regulatory is in development
- Large scale testing is a huge challenge

Coupled simulation models built on existing domain models and testing methods are needed



Desing hybrid power plant and grid integration process

Example for a large-scale system development

V-Model design approach

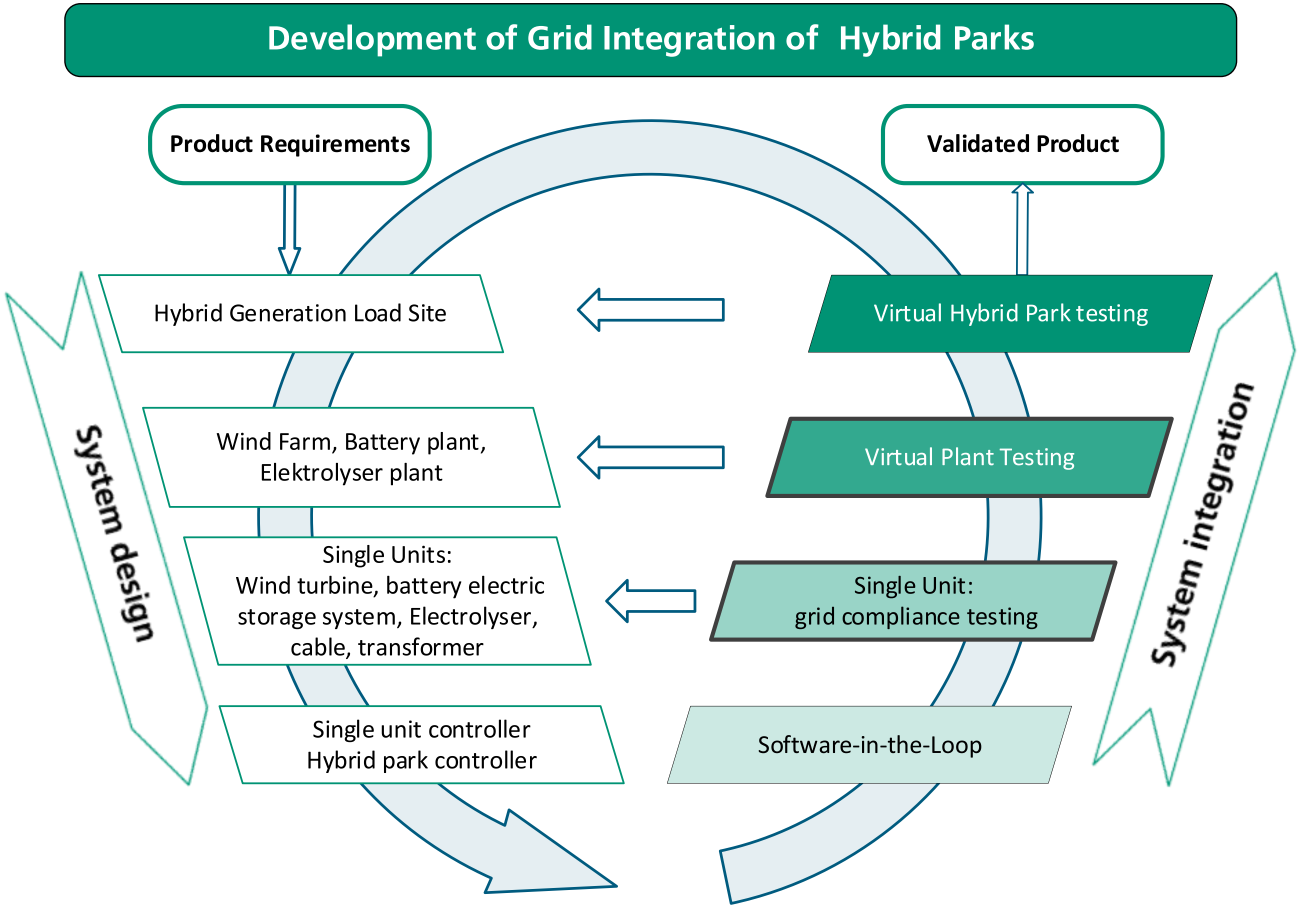
- each design specification level has a corresponding testing level

Requirements Analysis:

- Define acceptance tests to ensure final product meets requirements

System integration & system validation

- Validation must be planned during system design
- Validation of GW-scale will be done model based!
- Utilization of models in different levels of detail
- Models must cover many different domains



Fraunhofer IWES

Overview of Fraunhofer IWES testing infrastructure

Grid integration of wind turbines

Nacelle test bench

- 10/15MW Nacelle test bench
- 44 MVA Grid emulator
- Flexible utilization options
- Measurement of the electrical characteristics for type testing in the lab

Sub-system test bench

- 9/13 MW Generator-Inverter-System test bench for grid integration testing
- 44 MVA Grid emulator
- Validated Hardware-in-the-loop (HIL) system operation
- Measurement of the electrical characteristics for type testing in the lab

Mobile Grid

- 28 MVA / 80 MVA Grid emulator
- 66 kV for offshore application
- Mobile due to containerized setup - 19 container
- Enable grid Integration testing for upcoming offshore wind turbines including higher functionality

Multiple Available Test Pads - „Plug ‚n‘ Play“

- Each pad has power, data, H2, H2O & N2 at site
- Multiple pads can be combined
- Up to 10 MW

Fraunhofer IWES contribution to manage a large-scale system development

Q-Sim: Simulation Platform

The Platform is based on Co-Simulation

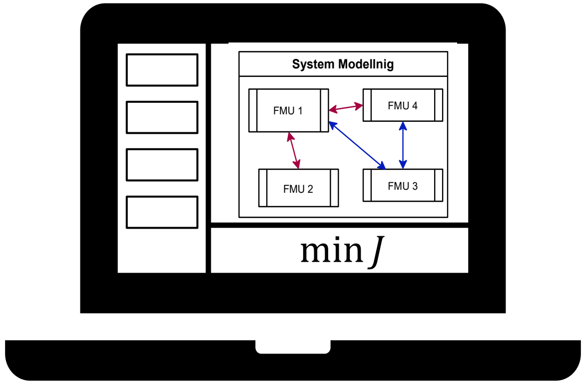
- Q-Sim is a dynamic simulation platform
- Implementation in Python
- Simulations are assembled by combining components into the larger system model
- Large simulations with many components are parallelized
- Abstraction of model interfaces for simplifications
  - enables parallel development of components
  - ensure compatibility between single simulation models

Scenario based simulations in the time domain

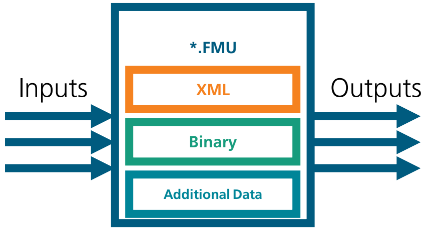
- Scenarios can be run in parallel

Requirements

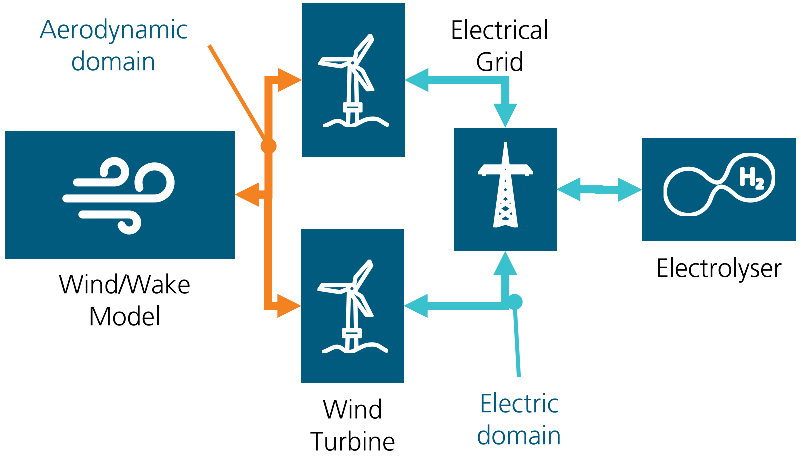
- All models must be implemented as FMU
- Interfaces between components are designed by a top-down approach



Functional Mock-Up Interface



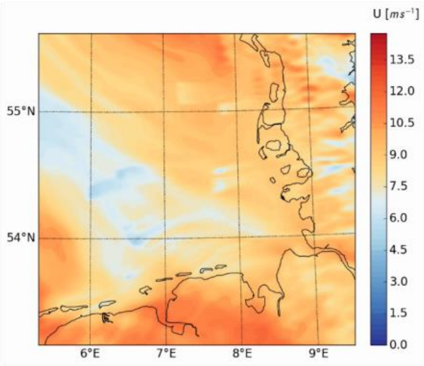
Example System:



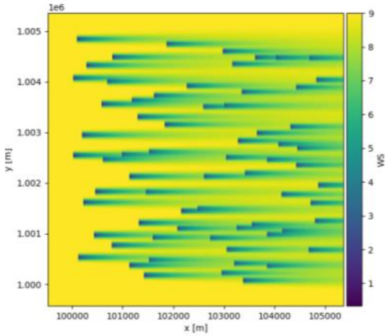
Fraunhofer IWES

Library of IWES component models

IWES component models cover the whole spectrum of wind energy conversion



Large-scale wind simulations

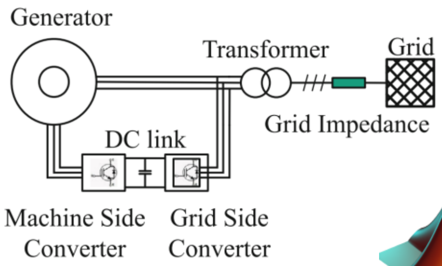


FOXES

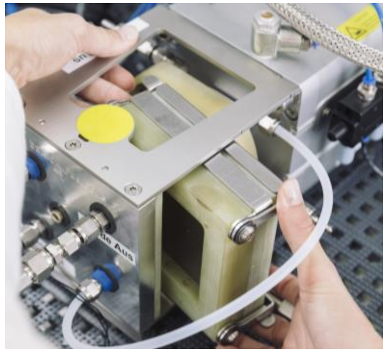
Local wind field in wind farm
https://github.com/FraunhoferIWES/foxes

Modelica

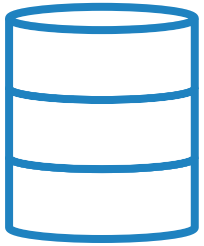
Aeroelastic wind turbine
http://www.mowit.info



Electrical drive train subsystem



Electrolyzer system

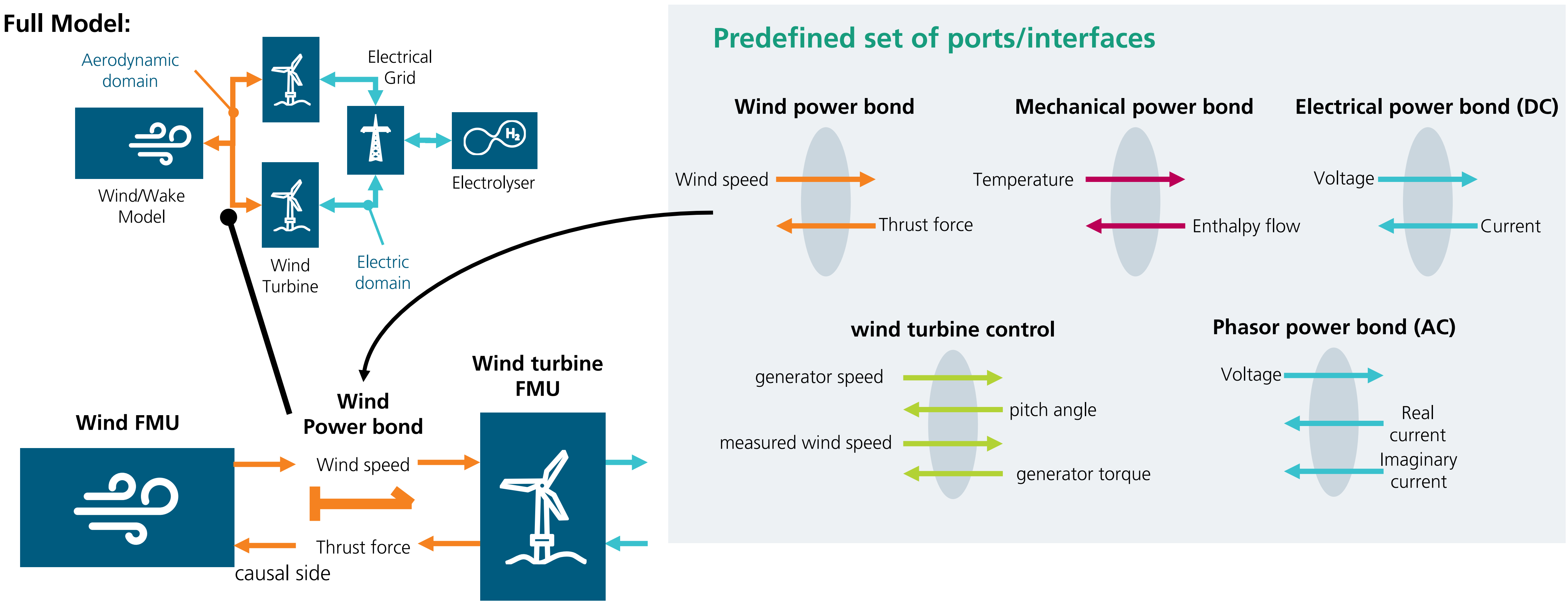


Database

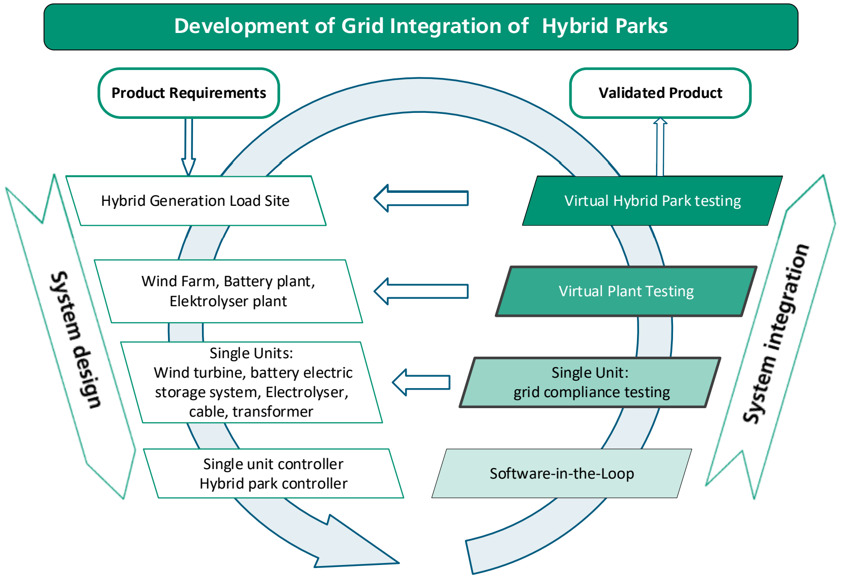
Fraunhofer IWES

Every models implements a predefined Interface

Interfaces are based on bond graph theory



Full System Definition

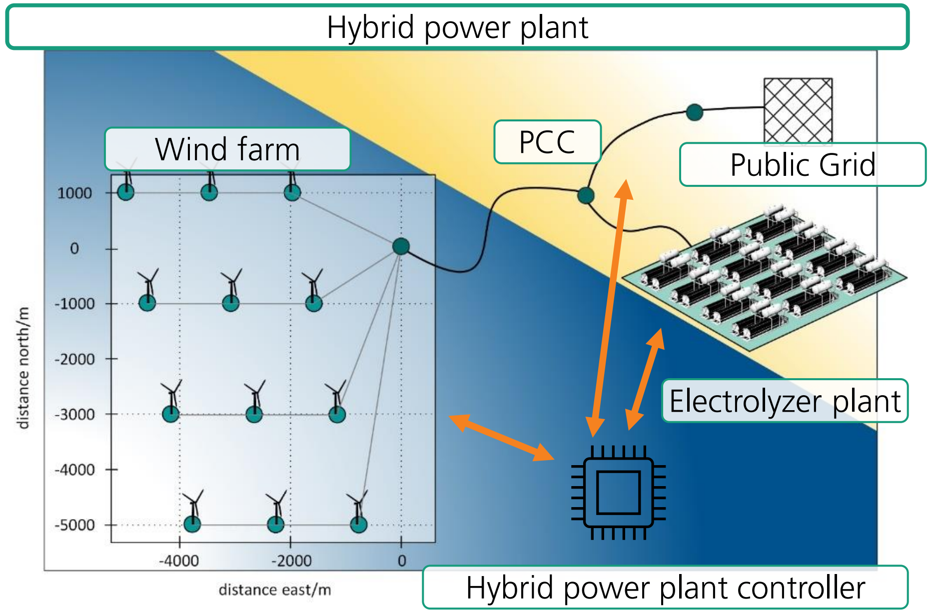


Dynamic simulation of a wind farm

- Hybrid wind farm control commands power setpoints of turbines and electrolyzer
- All simulation components are FMUs
- Interfaces for aerodynamic, electrical, thermic and controller domain

Hybrid Wind Farm:

- 12 offshore wind turbines in a grid layout
  - IEA 15 MW → 180 MW total
  - IWES Wind Turbine Research Controller
- 12 electrolyser units
  - 5 MW per unit → 60 MW total
- 15 cable models to transmit active and reactive power
- Hybrid wind farm controller
- Public grid model with variable voltage

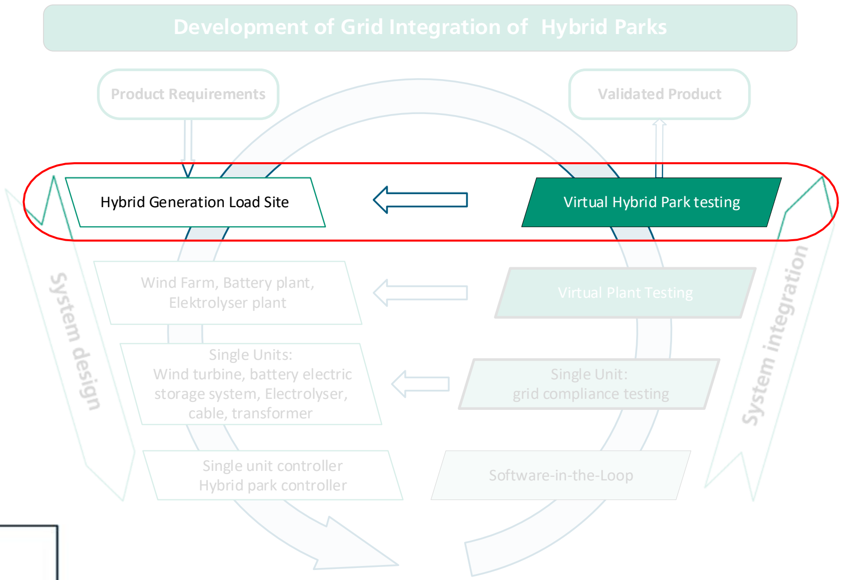


 1/13/2025

Fraunhofer IWES

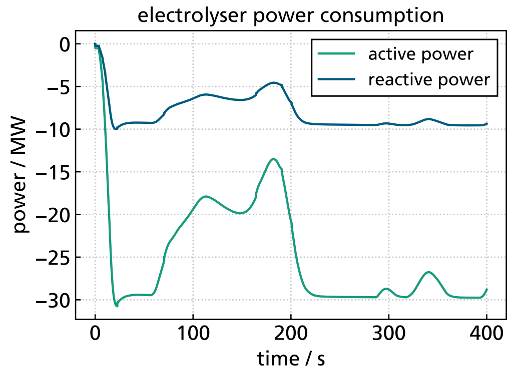
Hybrid Plant System Test

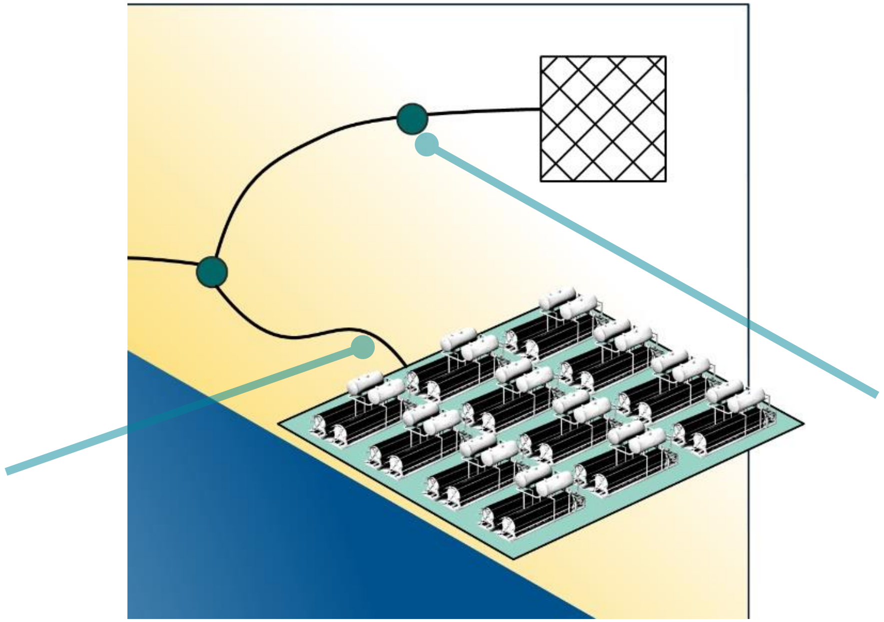
Virtual Hybrid Park Testing

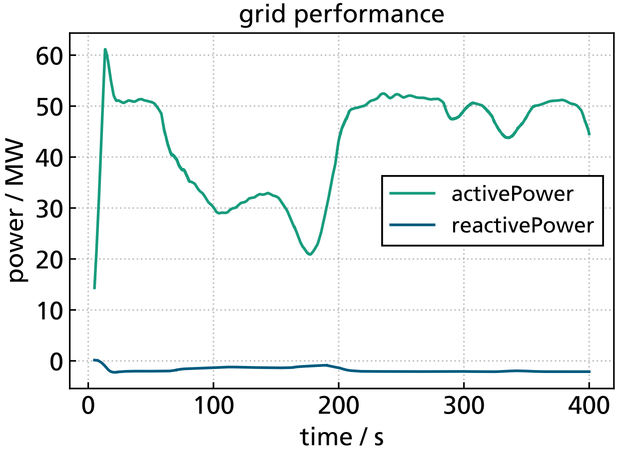


Overall performance of the system

- Total park performance is evaluated at the grid connection
  - Excess power is transmitted to the grid
  - Reactive power at the substation is close to zero
- Wind turbines compensate reactive power of electrolysers



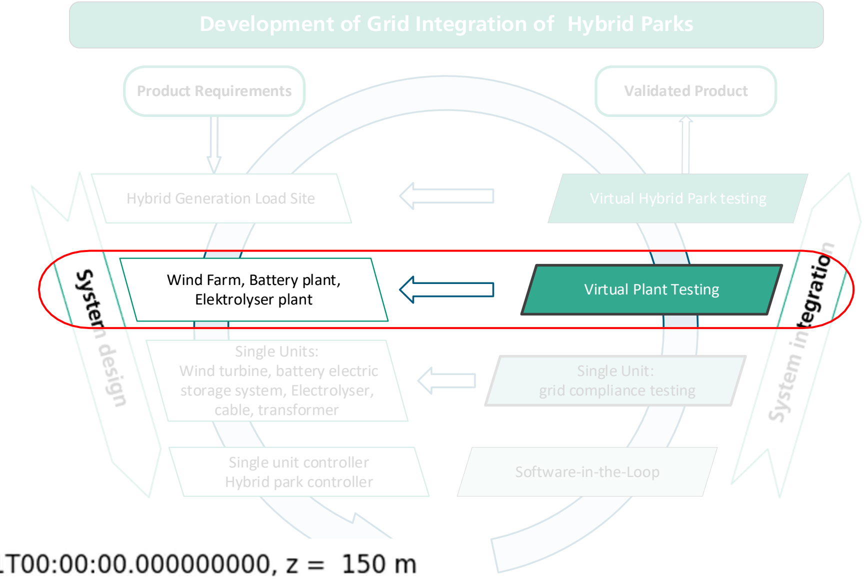




Fraunhofer IWES

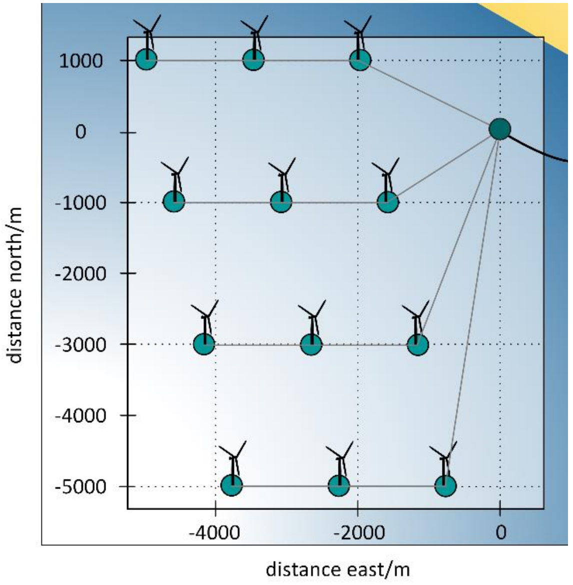
Wind Farm Power Plant

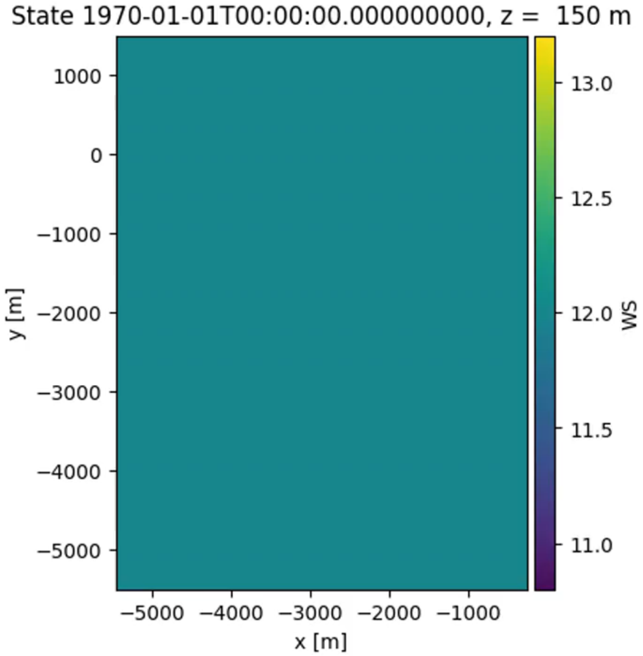
Virtual Plant Testing



Dynamic wind inflow

- Use an artificial wind field to show influence of wakes
- Include wake meandering effects
- Utilizing **Foxes** by Fraunhofer IWES for dynamic wakes
- Each turbine sees a difference wind profile
- Power is generated according to the wind farm controller



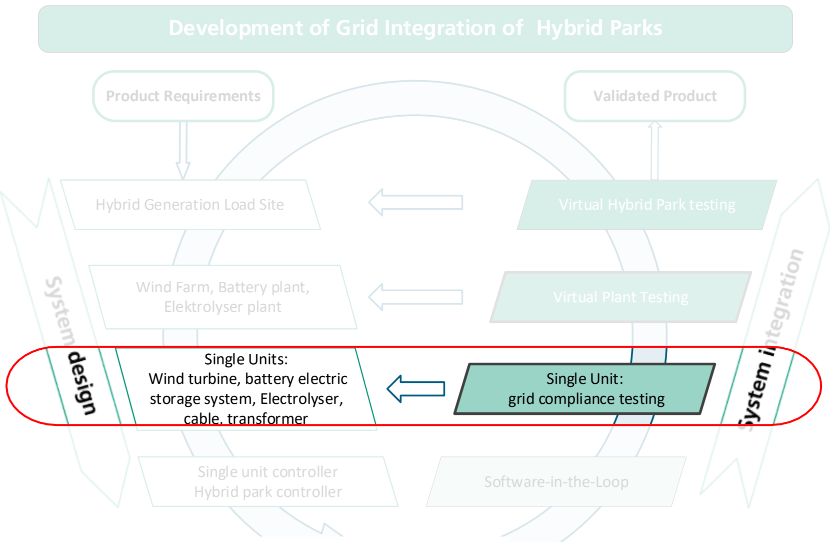


FOXES Fraunhofer

Fraunhofer IWES

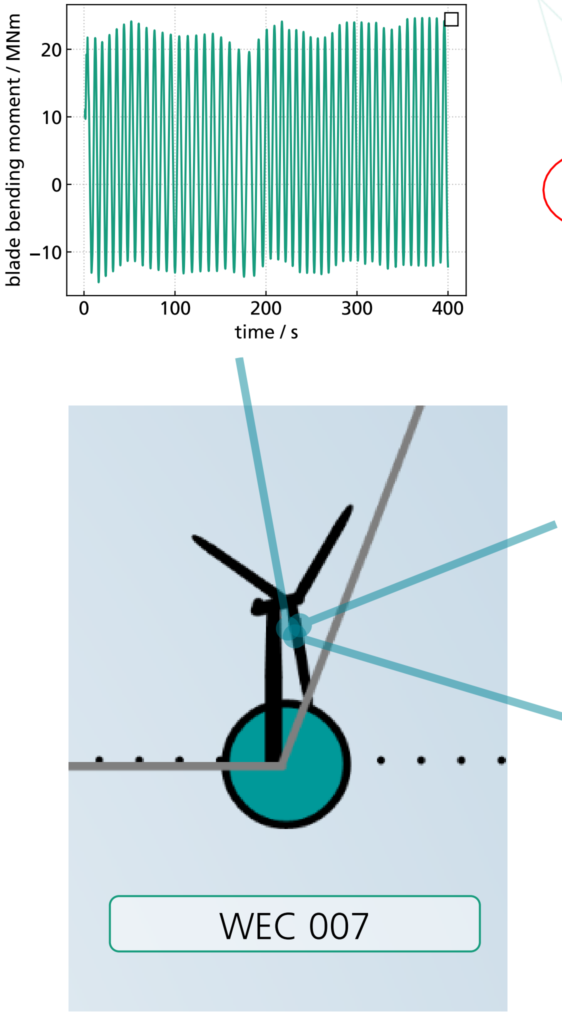
Detailed Model of the wind turbine

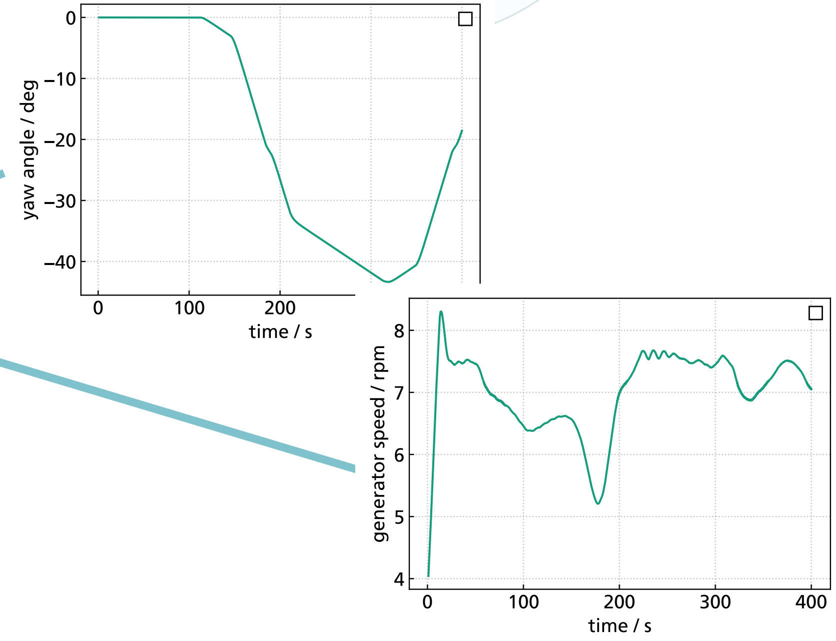
Single Unit Level



Wind turbine characteristics

- 15 MW IEA wind turbine
  - Implement different model fidelities
    - Wind turbine is an aero-elastic model
    - Simplified model
- Wind turbine is coupled to the grid by the generator system
  - The state of the grid can influence the turbine performance
- Wind turbine must be yaw to align with the wind direction
- Wakes and yawing cause a dip in available power

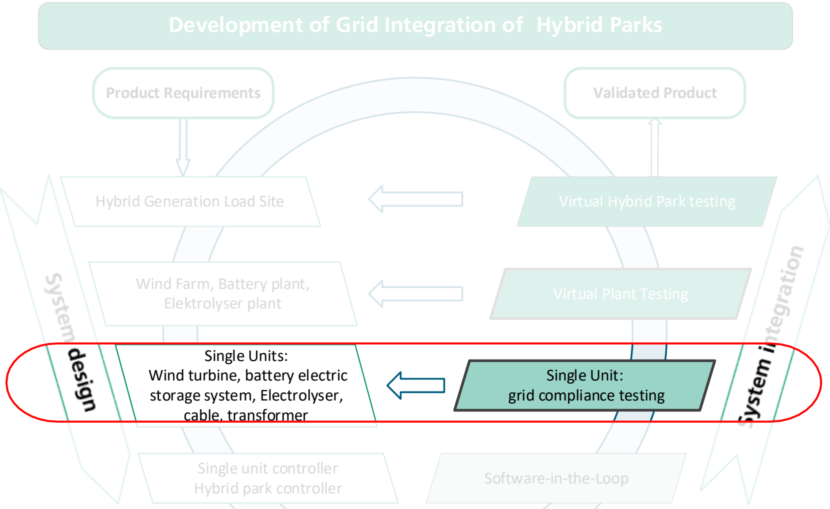




Fraunhofer IWES

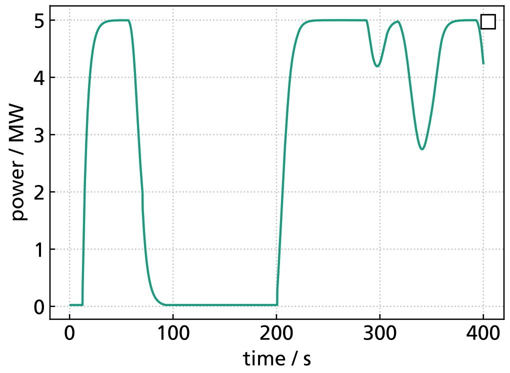
See all details of the electrolyser models

Single Unit Level



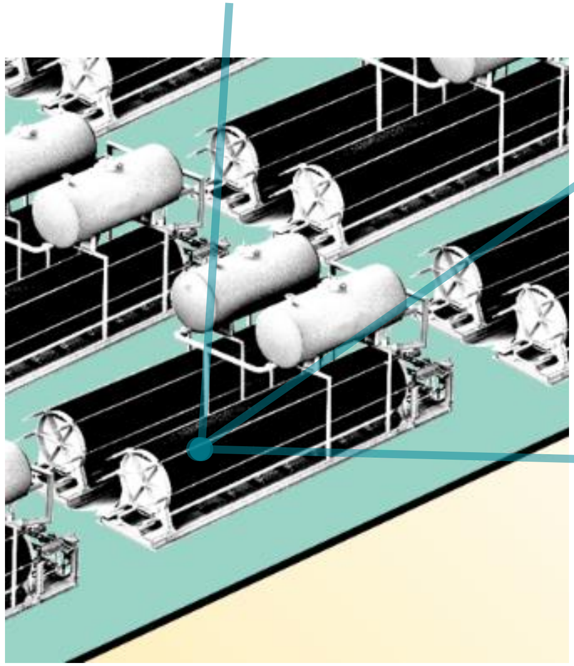
Dynamic performance of electrolyzer

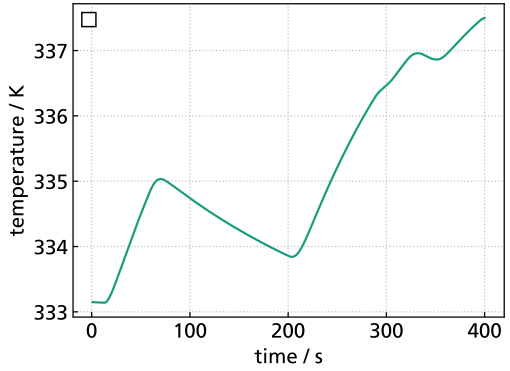
- Every electrolyser is calculated individually
- Each electrolyser receives a power setpoint

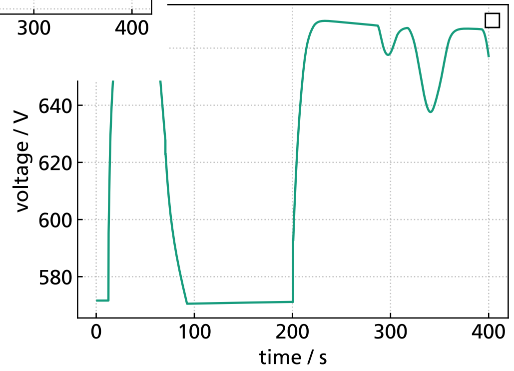


Single unit level enables decoupled development of components

- Components can be developed individually
- Predefined interfaces ensure that models can be connected later
- Level of detail can be chosen for each model







Base Component Development

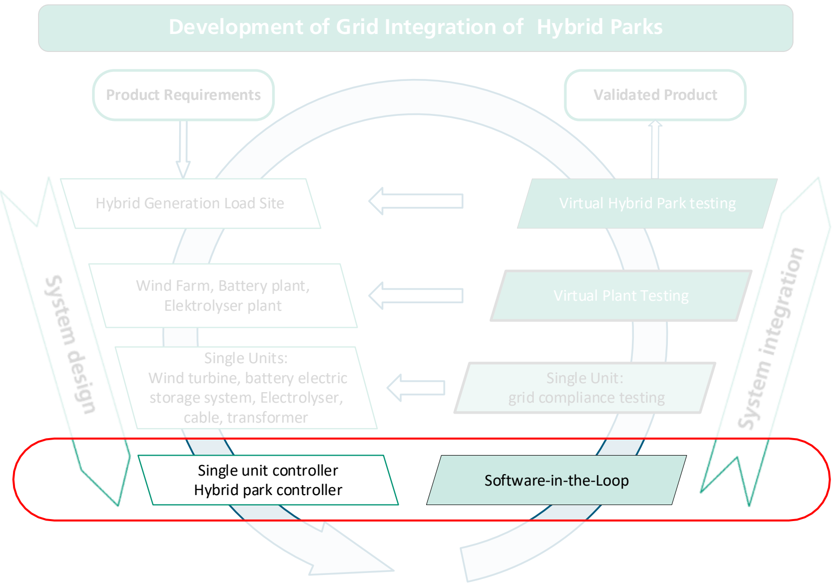
Component Level

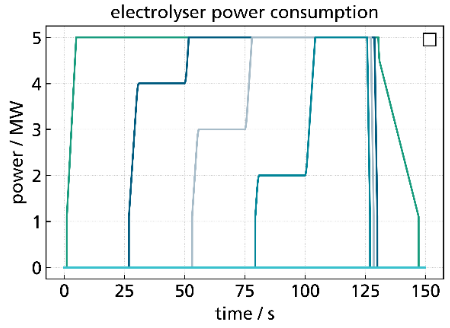
Individual components layer: Test all components individual before building the larger system

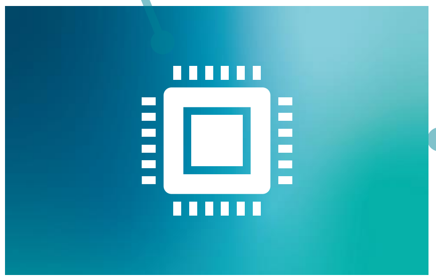
- The interfaces of components are designed
- Utilization of best suited modelling tool for each model
- Can be implemented fully virtually

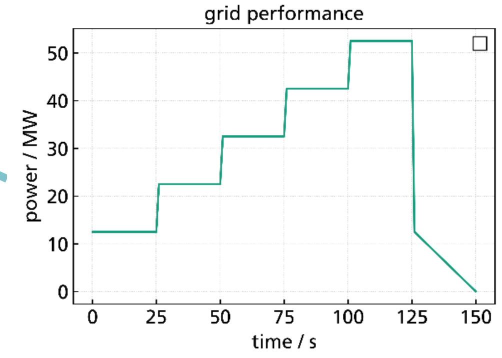
Testing is possible and required for development

- Development of single units
- After single unit validation, the larger simulation model can be built

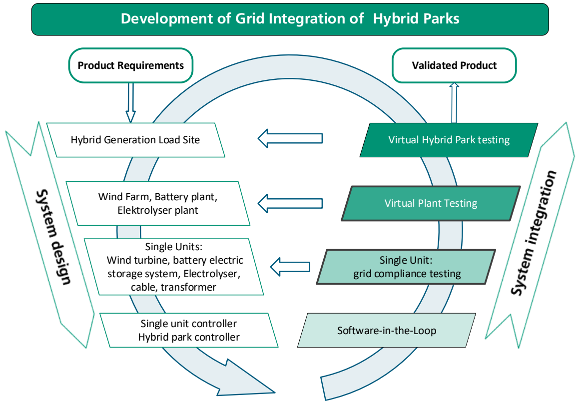






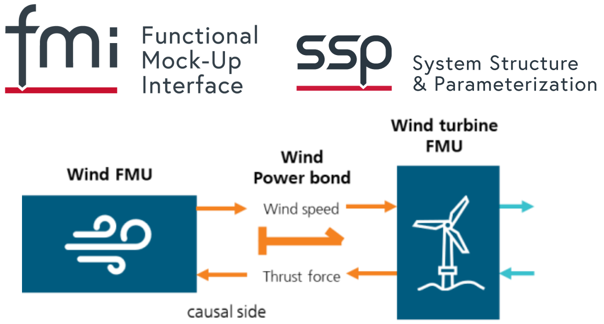


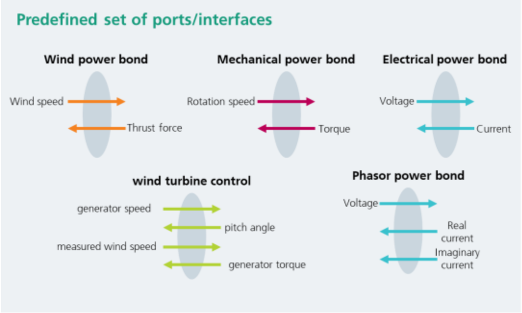
Summary



Structured Process for the development of large-scale systems

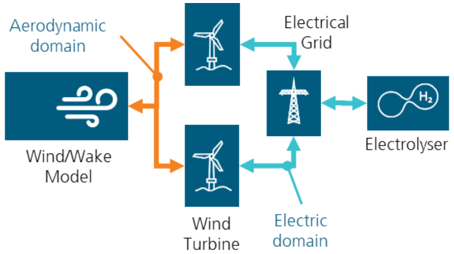
Co-Simulation basics and design of model interfaces





Define common interfaces to enable modularity for simulation models

Describe large scale models as a graph



Fraunhofer IWES

Thank you for your time!

Fraunhofer IWES

Contact

Marcus Wiens
Advanced Control Systems
Fraunhofer Institute for Wind Energy Systems IWES
Am Seedeich 45
27572 Bremerhaven
Germany

Phone +49 471 14290-461
marcus.wiens@iwes.fraunhofer.de