Model-Aided Design of a Hydraulic Pitch Actuation System

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Model-Aided Design of a Hydraulic Pitch Actuation System

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Introduction

What is Dymola / Dymola Behavior Modeling

Determining the Performance Requirement

Pre-sizing Process

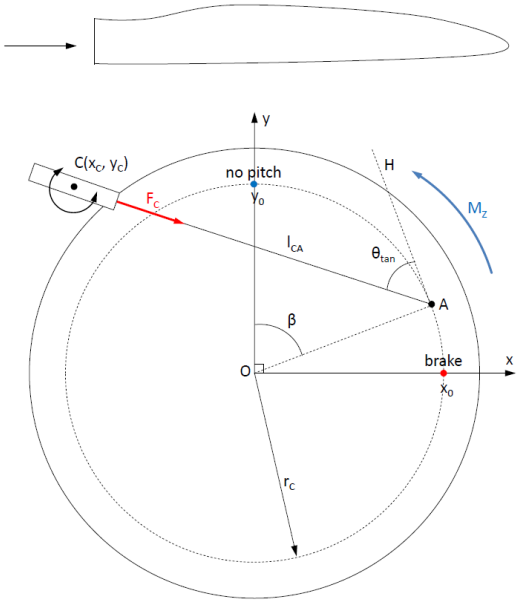
Modeling and Simulation: Unitary and Integration Tests

Conclusion and Perspectives

Introduction

Pitch Actuation of a Wind Turbine Blade

- Fulfill several functions:
  - Power modulation
    - Collective Pitch Control (CPC)
    - Individual Pitch Control (IPC), e.g. for load alleviation
  - Aerodynamic braking
- Safety critical functions
- Need for High Power → usually hydraulic solutions:
  - Linear cylinder
  - Mechanical kinematics



Introduction

Additional contributors to this work

- Part of the *Design Process* project was lead in the scope of a Master Thesis
  - Student: Fengyu Chen
  - Technical University München: Wind Energy Institute.
  - Recorded pitch scenarios provided by WEI.

- Integration Tests were the result of collaboration inside Dassault Systèmes
  - Steve Mulski
  - Simpack team

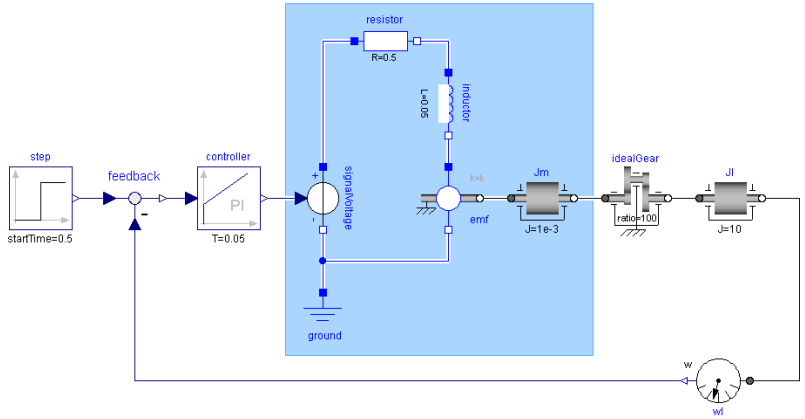
Model-Aided Design of a Hydraulic Pitch Actuation System

Dymola / Dymola Behavior Modeling

1-D Modeling and Simulation Software

- Modelica language
  - Equation based
  - Acausal
  - Declarative
  - Object-oriented
  - Non-proprietary
  - Allows external interfacing

- Dymola: Text editor and Graphical interface



- DBM: Dymola on 3DExperience platform

Dymola / Dymola Behavior Modeling

Combined Structural / Symbolic / Numeric Solver:

- Structural Processing
  - Based on graph theoretical methods
  - Well suited for large problems (hundred thousands of equations)
- Symbolic Manipulation - Specialized computer algebra specialized for large dynamic models
  - Sorts equations
  - Solves equations symbolically
  - Generates symbolic Jacobians for efficiency
  - Handles DAE with constraints (high index DAE's)
  - Transforms equations to efficient C-code
- Numeric
  - Special methods for hardware-in-the-loop simulations

Dymola / Dymola Behavior Modeling

Symbolic Manipulation

- Original equations
- Alias removal
- Trivial equations removal
- First BLT
- Identification of the singularities
- Simplification of some singularities
- Finally: BLT partitioned

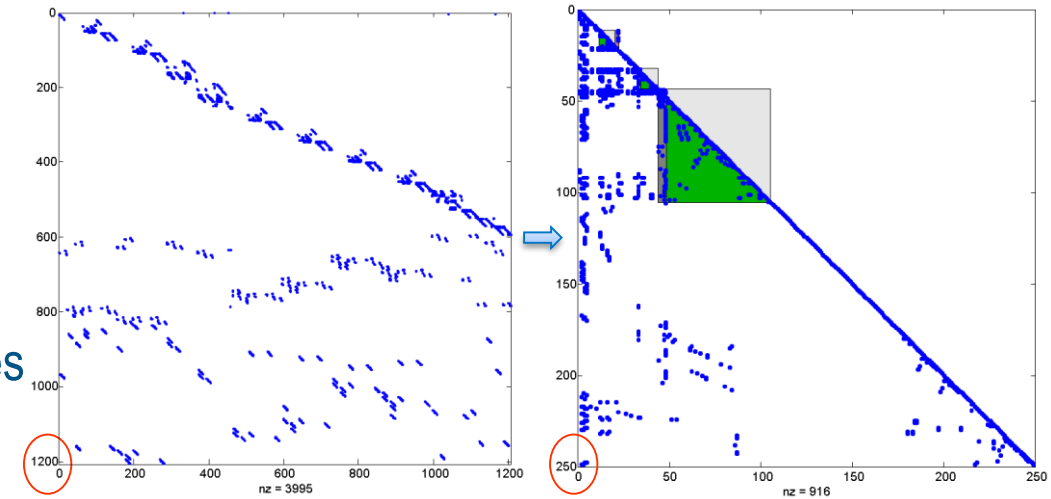
Structure Jacobian

Horizontal axis: variables

Vertical axis: equations

nz: number of markers (blue dot)

Marker in (i,j) if the equation j contains variable i



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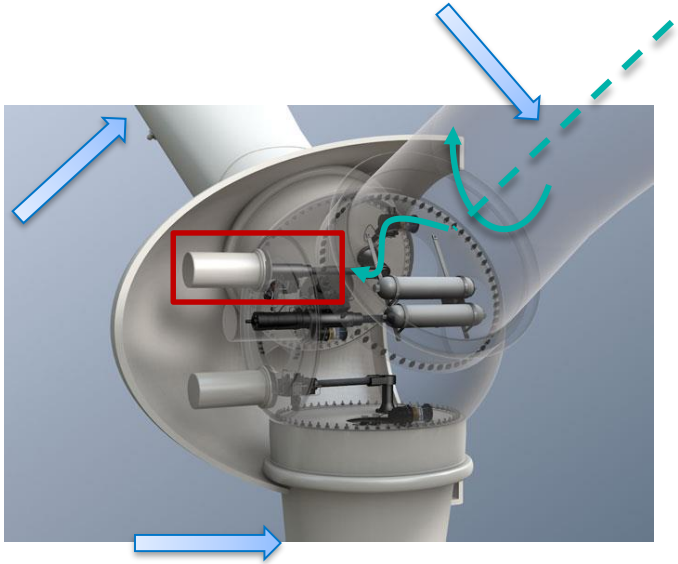
Determining the Performance Requirement

From the aerodynamic loads to the hydraulic cylinders



From blade position/speed scenarios

Computation of aerodynamic loads: collective or individual

Induced mechanical torque on blade roots

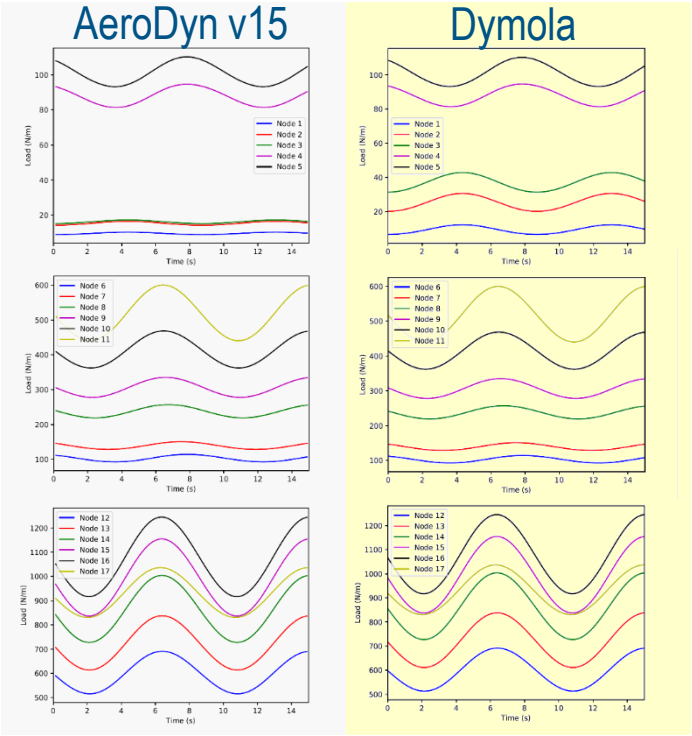
Induced mechanical force on each pitch actuator

Sizing of hydraulic system (pump, pipes, valves, actuators…)

Determining the Performance Requirement

Computation of aerodynamic loads

- Rotor model
  - Yawed rotor
  - Skewed wake affecting only axial velocity
  - Blade Element Momentum Theory (BEMT)
  - An iterative method
- Simulation results
  - Node 1 at root, Node 17 at tip
  - Good correlation
  - Negligible first 3 nodes (near rotor, cylinder shape)

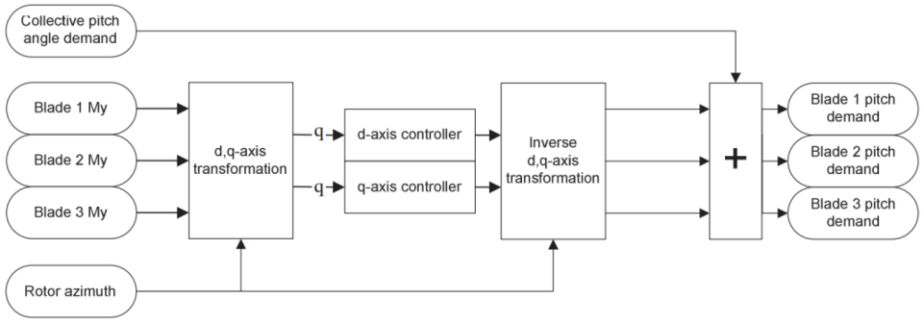


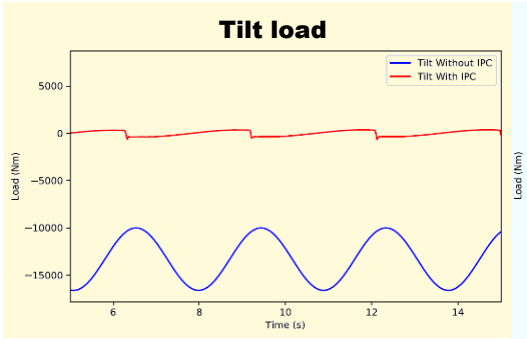
Validation: wind speed 3m/s; rotor speed 6.9 rpm; wind inflow angle 10 deg

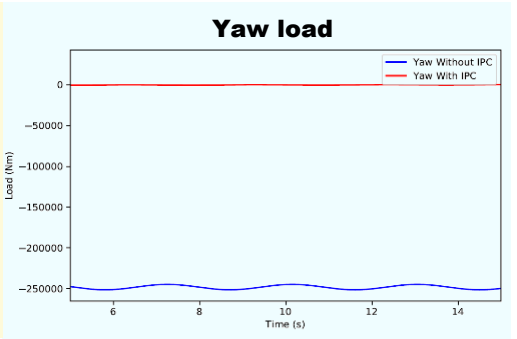
Determining the Performance Requirement

Computation of aerodynamic loads

- From CPC to IPC
  - Demodulate blade root load
  - Controllers computing the desired tilt and yaw angles
  - Re-modulate tilt and yaw angles







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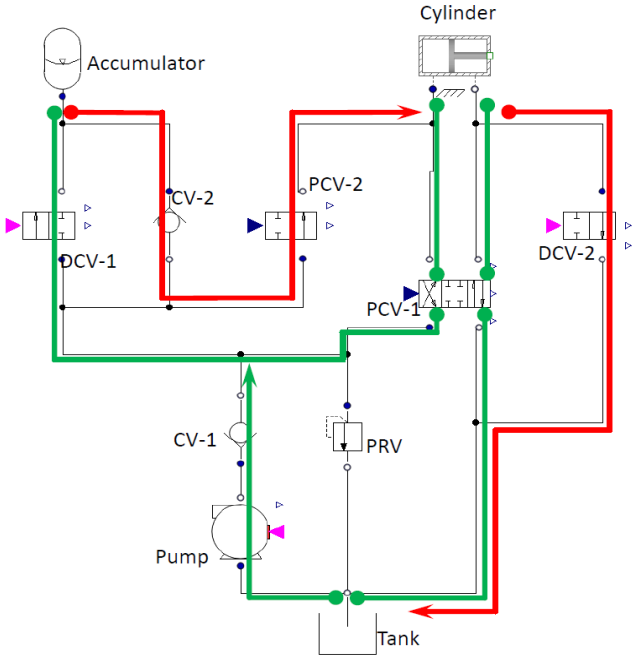
Pre-sizing Process

Hydraulic system architecture

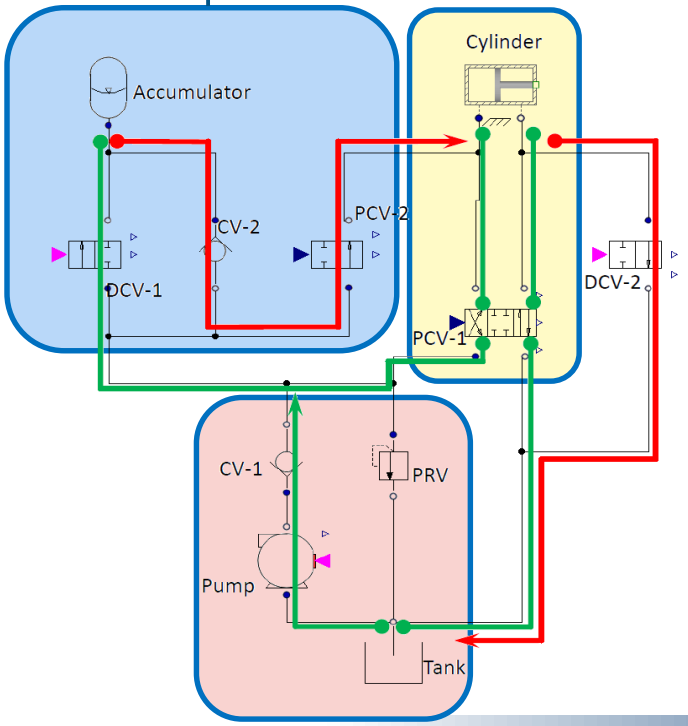


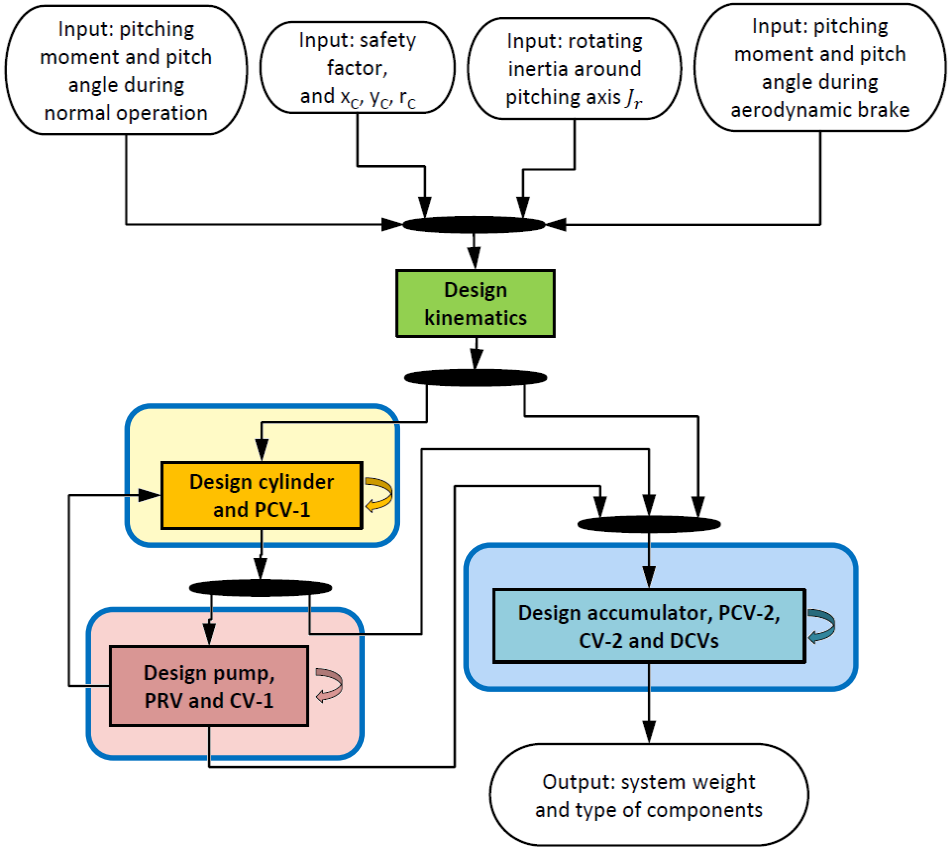
- Architecture similar to EP 2 458 203
- Hydraulic Power Generation
- Hydraulic Power Storage
- Hydraulic Power Modulation
- Hydraulic Power Transformation

- Nominal scenario
- Emergency braking scenarios

Pre-sizing Process

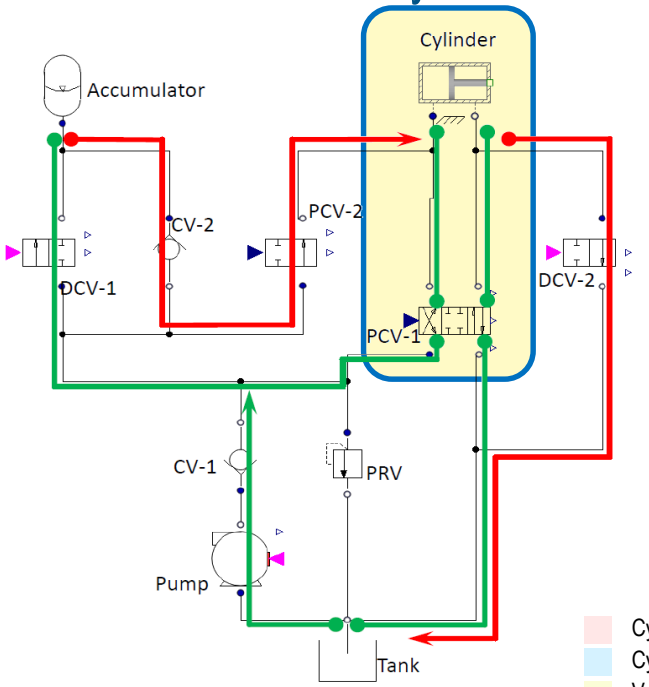
Overall process



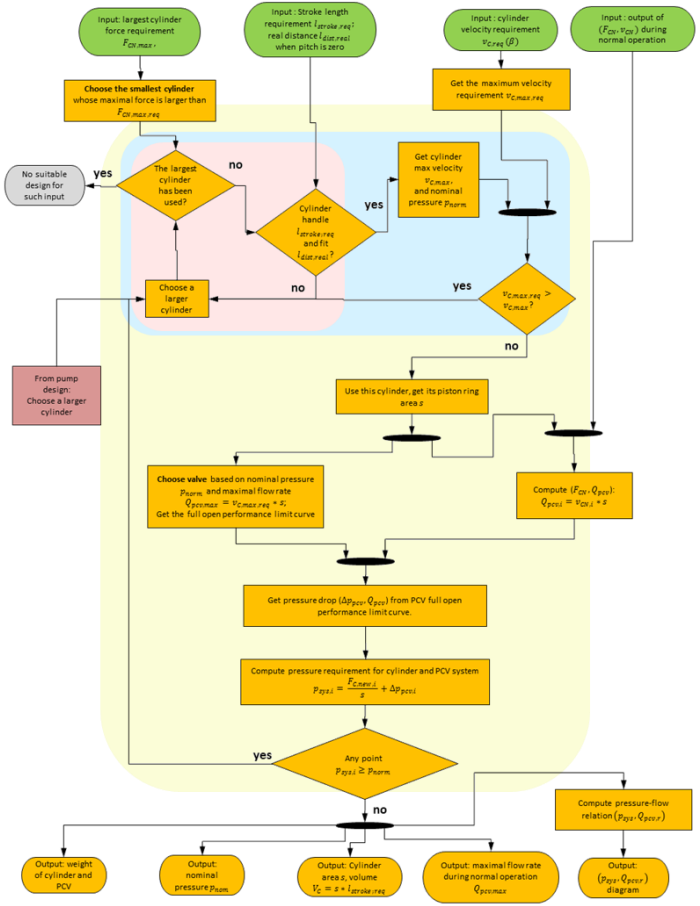


Pre-sizing Process

A closer look at the cylinder/valve design process



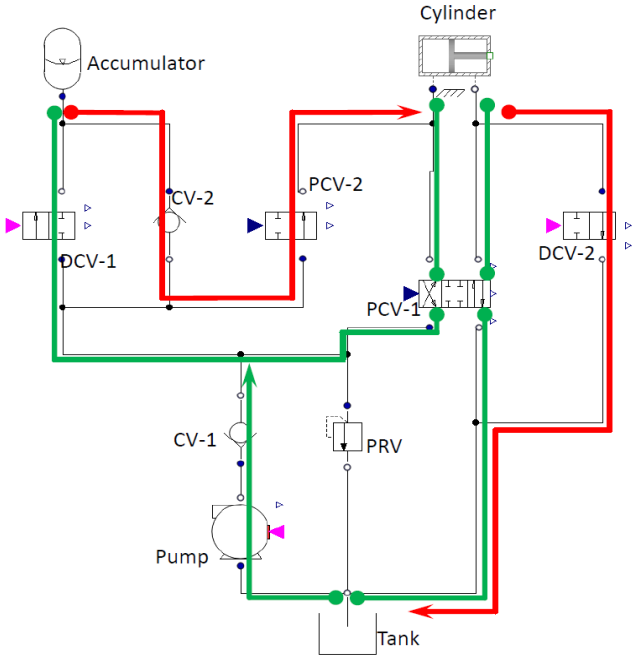
- Cylinder design: Maximum force requirement
- Cylinder design: Maximum speed requirement
- Valve design



Design process: cylinder and PCV-1

Pre-sizing Process

Summary



- Based on physical laws of components
- Design process implemented in Excel for the proof of concept
- Automatic selection of components from provider datasheets (e.g. Bosch Rexroth, Parker, Moog…)
- Model parametrization based on datasheets
- Compute total weight
- Simulation of scenarios for design validation

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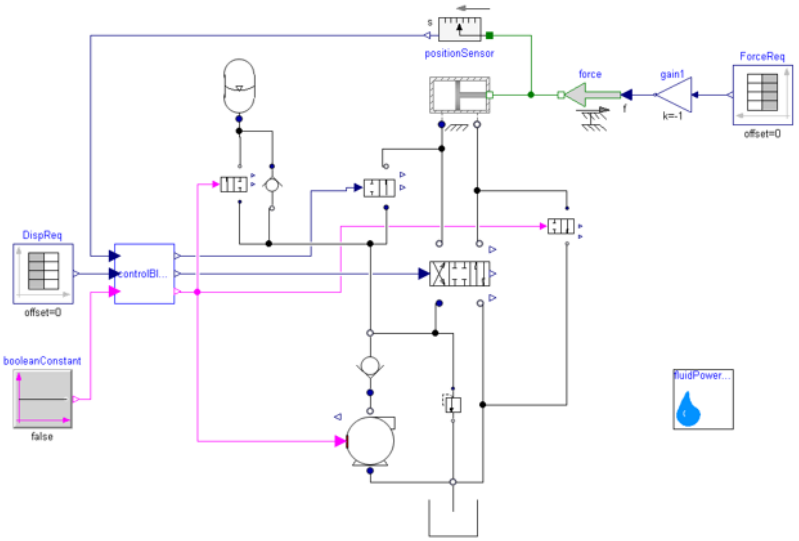
Modeling and Simulation

Unitary tests in Dymola

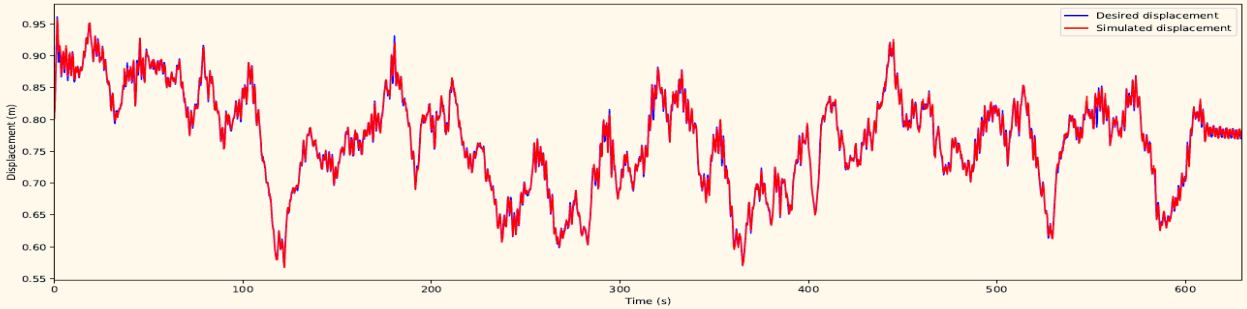


- Model parameters from datasheets
- Scenarios as inputs
- Run simulations in Dymola

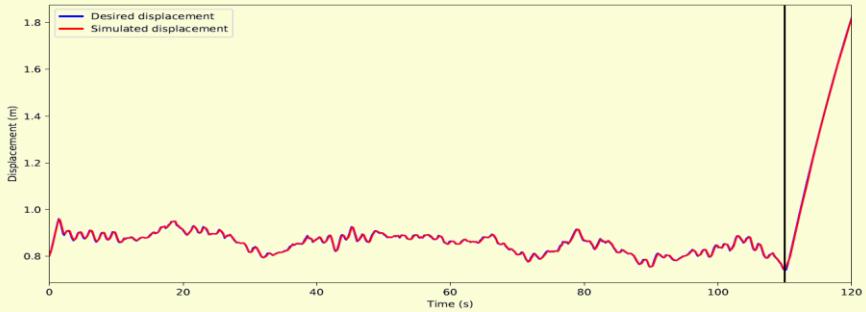
Modeling and Simulation

Unitary tests in Dymola

Nominal operation



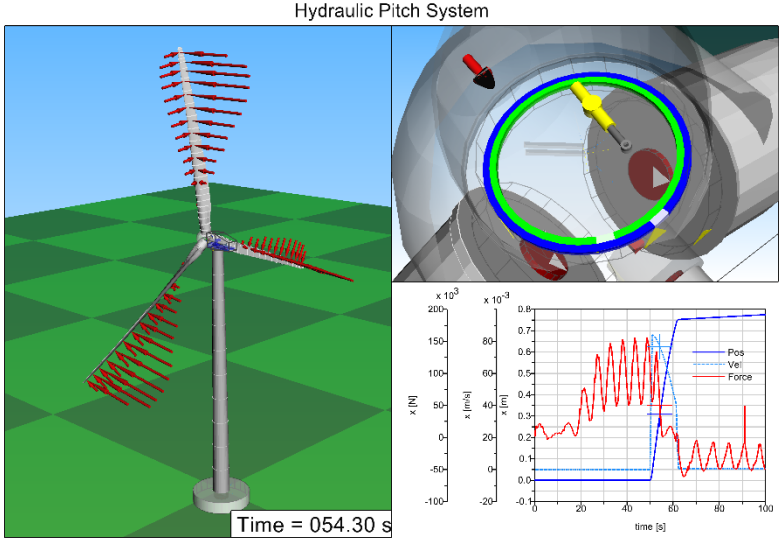
Aerodynamic brake



Modeling and Simulation

Integration tests

- Dymola model exported as an FMU
  - FMI standard (co-simulation)
  - No license call (source code generation)
- Integration into Simpack
  - Complete Wind Turbine model
  - Integration tests performed



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Conclusion & Perspectives

- Demonstrate the use of Dymola for pre-sizing a hydraulic actuation system
  - From load computation to hydraulic system simulation
  - Operational and emergency scenarios
  - Model export for deep integration tests

- Perspectives
  - The pre-sizing process will be implemented into the 3DExperience Knowledgeware
  - Model realism reduction for behavior fitting in HIL simulation

Thank you for your attention

Questions?