Mechanical Hardware-in-the-Loop Systems for a Wind Turbine System Test Bench

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Agenda

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Center for Wind Power Drives at RWTH Aachen University

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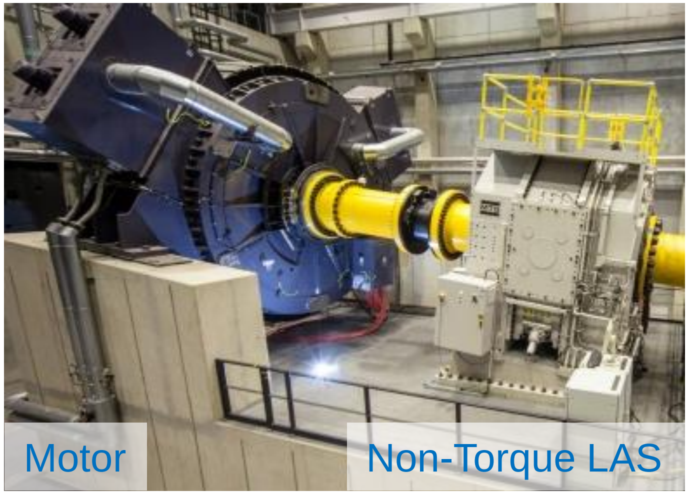
- www.cwd.rwth-aachen.de
- www.rwth-aachen.de

Center for Wind Power Drives
Wind Turbine System Test Bench



- Mechanical Load Application System
  - Motor
    - Direct Drive
    - $P_{\mathrm{r}} = 4\ \mathrm{MW}$
    - $M_{\mathrm{r}} = 2.7\ \mathrm{MNm}$
  - Non-torque
    - 5 degrees of freedom
- Electrical System
  - Grid Emulator

- Research Wind Turbine
  - NEG Micon NM 80
    - $P_{\mathrm{r}} = 2.75\ \mathrm{MW}$
    - Was in operation in north Germany
  - Automation and control self-developed and implemented
    - Can be changed at any time
    - No publication difficulties

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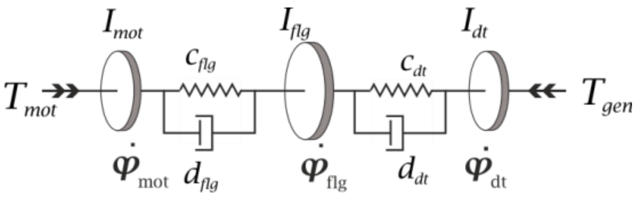
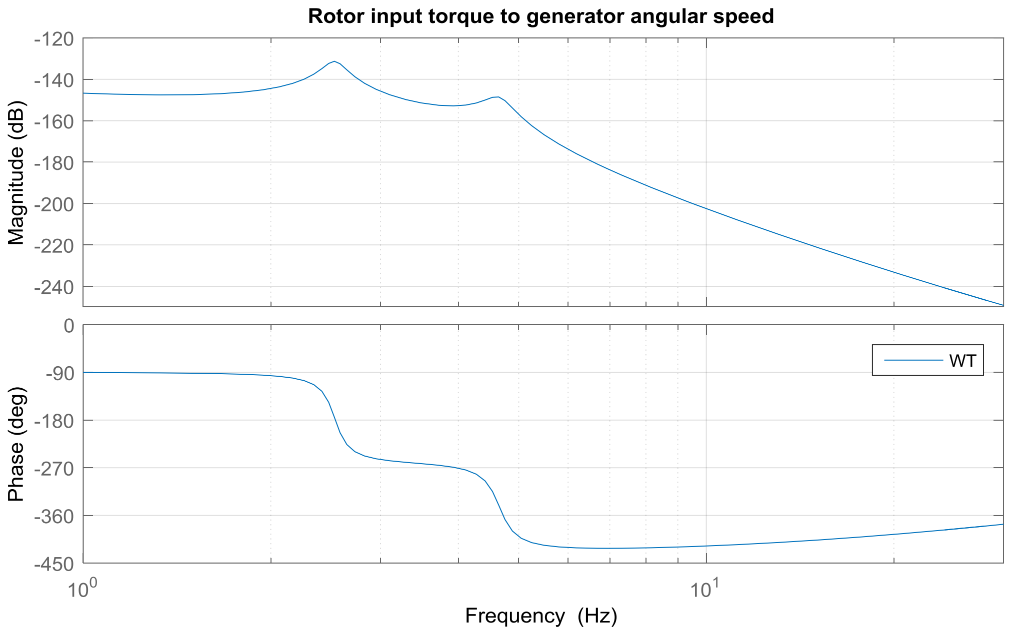
Motivation Wind Turbine System Test Bench

- Advantages
  - Time, no waiting for wind
  - Freely definable test, no limit to site specific conditions
  - Reproducibility
  - Cost?
- Disadvantage
  - Realistic loads?
- Open questions
  - Certification?
    - ➢ New Project Cert Bench Systematic Validation of System Test Benches by Type Test of Wind Turbines
  - What dynamic must and how can it be reproduced?

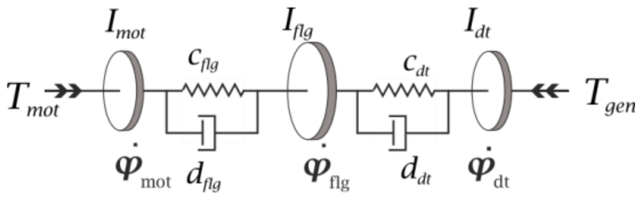
Wind Turbine System Test Bench
Model of the Wind Turbine

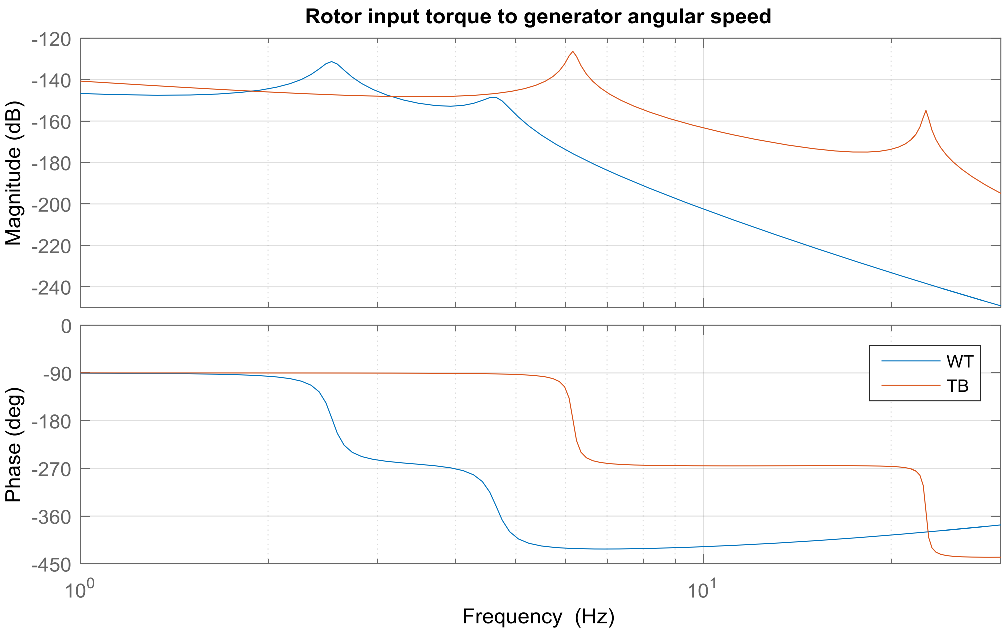




- Concentrated parameter model
  - Inertia, spring and damping constant
  - Parameters derived from multi-body simulation and experiment
- Three inertia oscillator
  - First two eigenfrequencies

Wind Turbine System Test Bench
Dynamic of the Wind Turbine on the System Test Bench

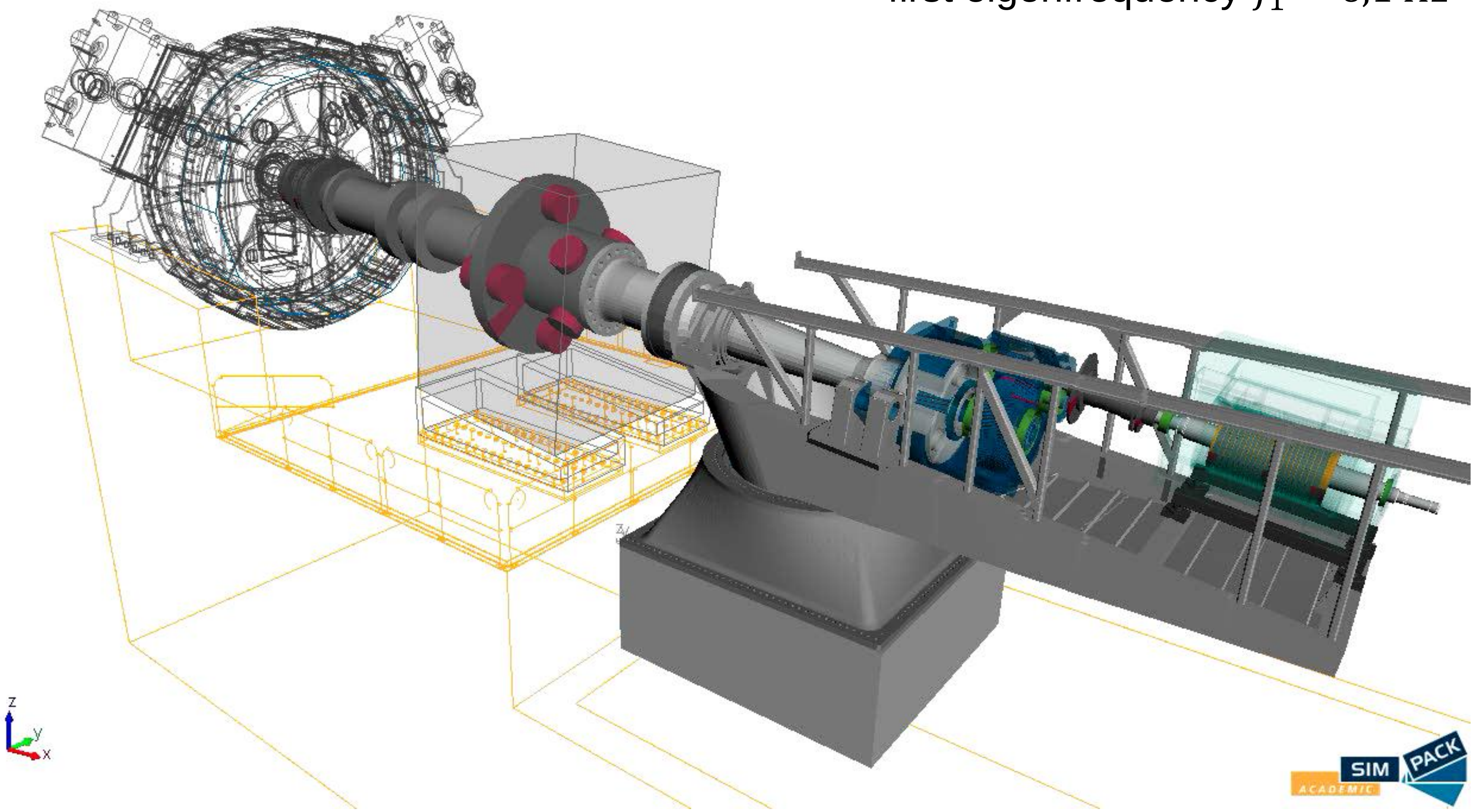




- Mechanical dynamic of the Wind Turbine different from the one on the Test Bench due to different
  - Inertia, especially of the rotor!
  - Spring and damping constants
- Aeroelastic torque too big for Wind Turbine without rotor
  - Instable test bench operation

Wind Turbine System Test Bench
Multi-Body Simulation

first eigenfrequency $f_1 = 6{,}1\ \mathrm{Hz}$



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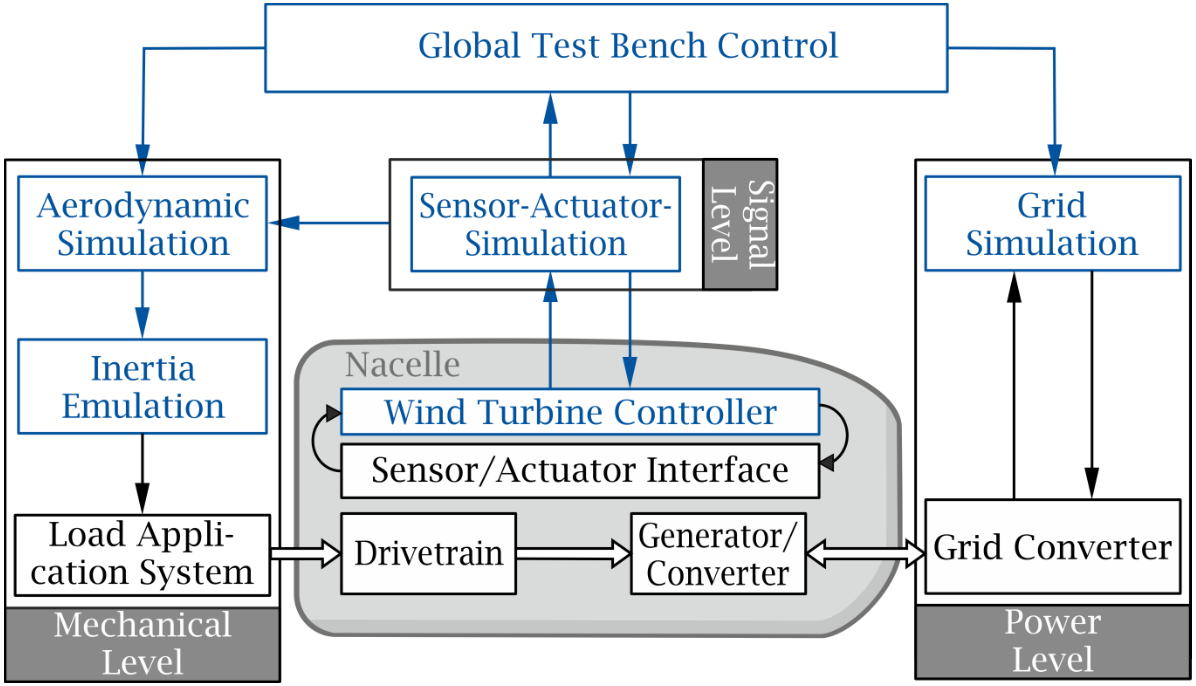
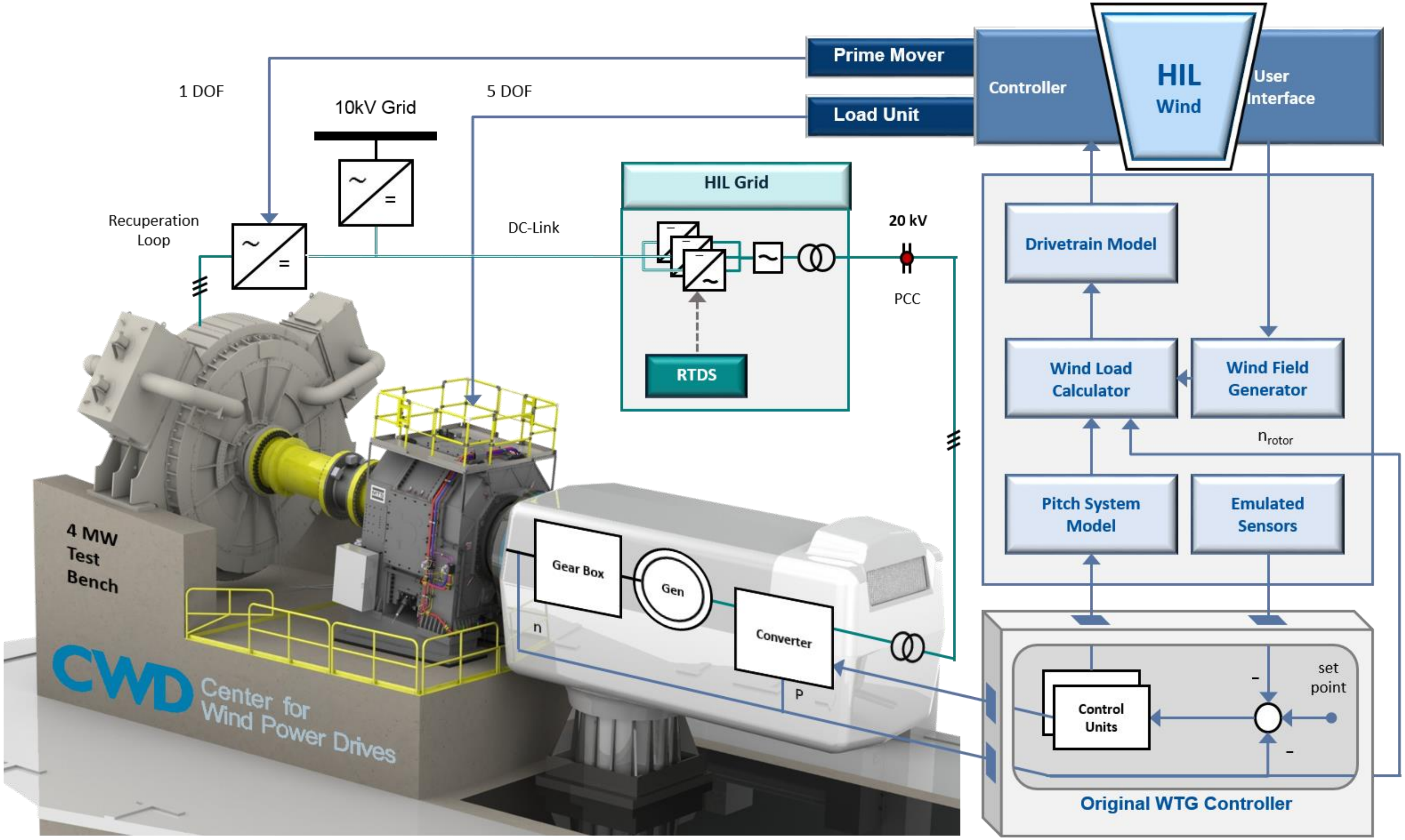
Mechanical Hardware in the Loop Systems
Hardware-in-the-Loop Environment



- Embedding of the Wind Turbine in a Hardware-in-the-Loop environment
  - Signal HIL: reproduction of the sensor + actuator dynamic on signal level
  - Power HIL: reproduction of the realistic electrical dynamic on power level
  - Mechanical HIL: reproduction of the realistic mechanical dynamic on power level
- Opposing challenges as always in control
  - Accuracy
  - Robustness

Mechanical Hardware-in-the-Loop Systems
Mechanical Hardware-in-the-Loop System at the System Test Bench



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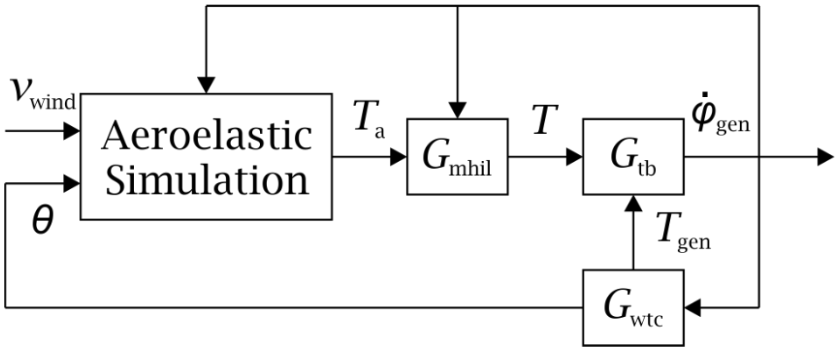
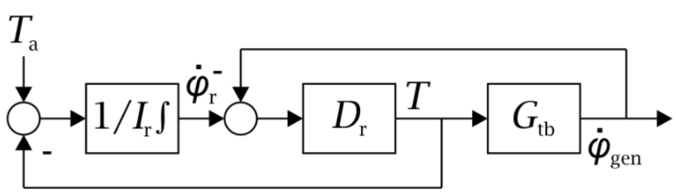
Inertia Emulation



- Emulation of the rotor inertia
- Virtual inertia damping system
- Validation in simulation and experiment several yeas ago on a smaller system test bench
- Stable operation, but no reproduction of the dynamic

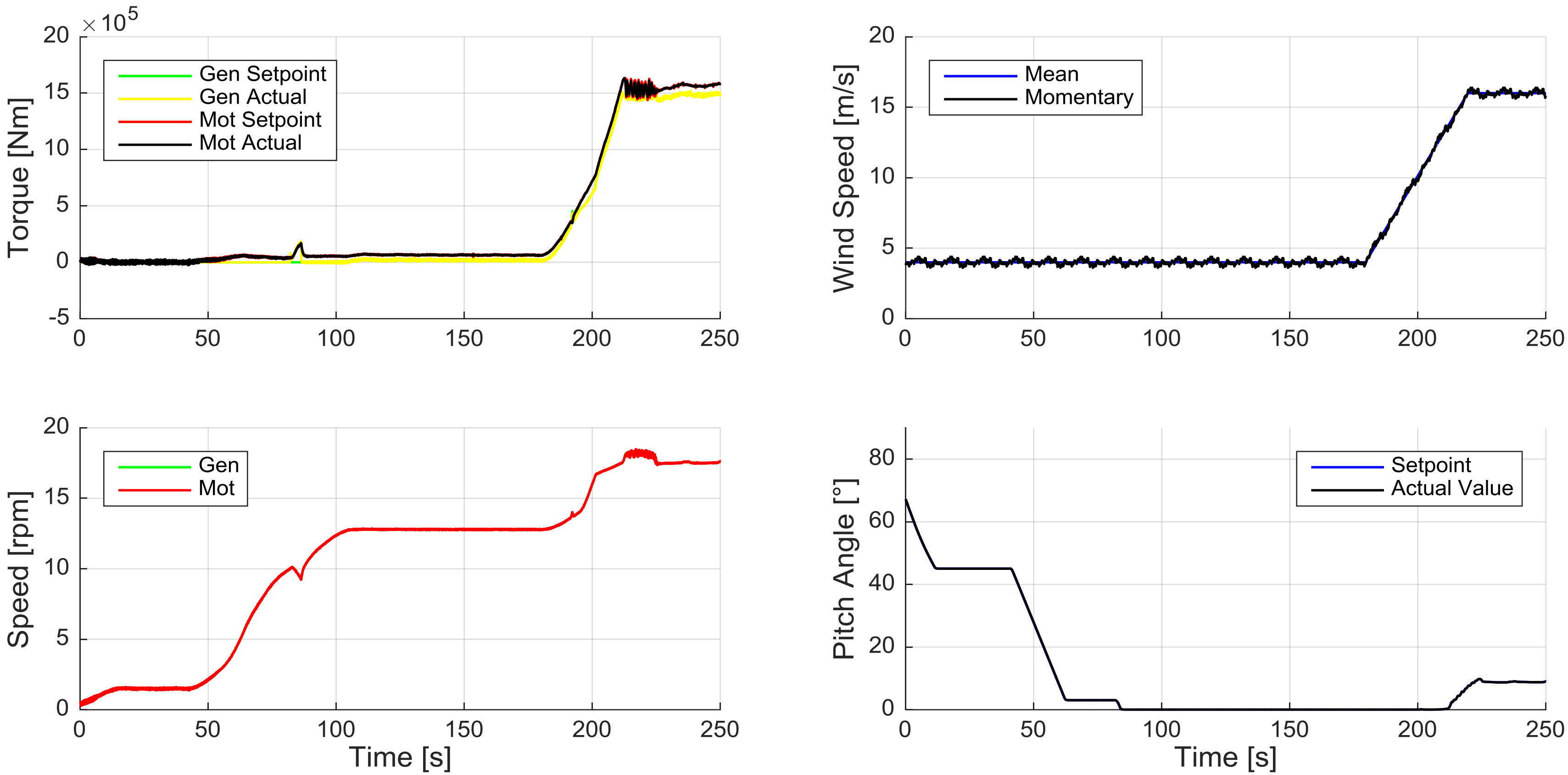


U. Jassmann, M. Reiter, D. Abel
An Innovative Method for Rotor Inertia Emulation at Wind Turbine Test Benches
IFAC World Congress, 2015

U. Jassmann, M. Hakenberg, D. Abel
An Extended Inertia and Eigenfrequency Emulation for Full-Scale Wind Turbine Nacelle Test Benches
IEEE International Conference on Advanced Intelligent Mechatronics (AIM), 2015

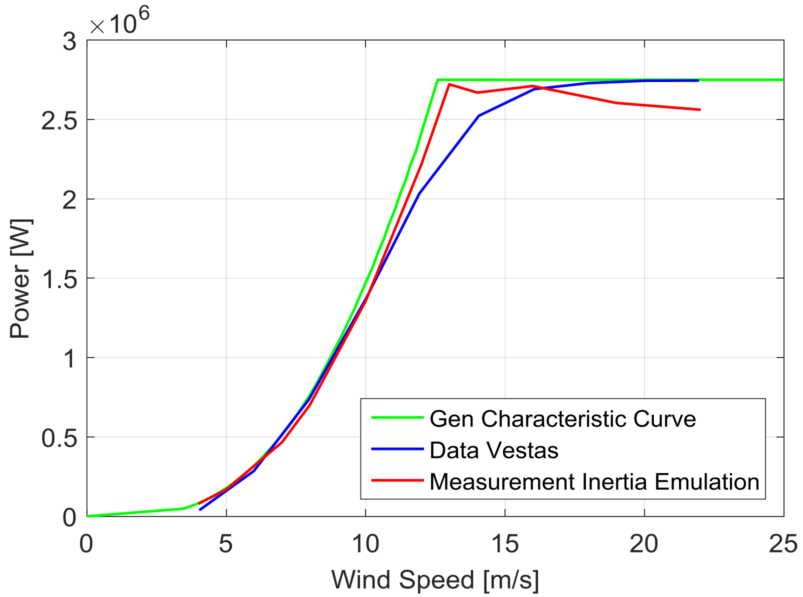
C. Leisten, U. Jassmann, D. Matzke, M. Hakenberg, R. Schelenz, D. Abel, G. Jacobs
An improved inertia-eigenfrequency emulation for a wind turbine system test bench
TORQUE, 2016

Inertia Emulation
Validation in experiment



- Test on April 6 2017

Inertia Emulation
Validation of the power curve in experiment



- Very good agreement with data from Vestas and the generator power curve
- Generator power curve calculated from characteristic diagram of the power coefficient according to FAST User's Guide of the National Renewable Energy Laboratory
- Characteristic diagram calculated from aeroelastic simulation

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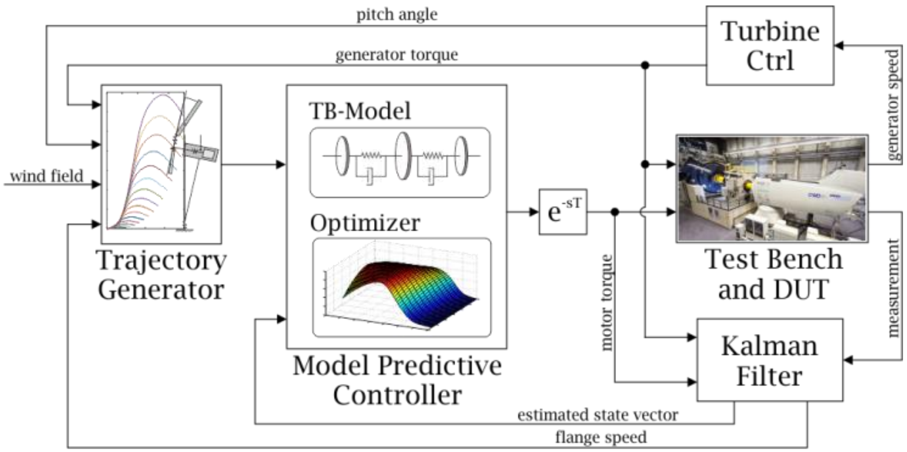
Inertia Eigenfrequency Emulation

Model Predictive Control



- Publication at
  IFAC World Congress 2017

C. Leisten, U. Jassmann, J. Balshüsemann, M. Hakenberg, D. Abel
Design and Analysis of a MPC-based Mechanical Hardware-in-the-Loop System for Full-Scale Wind Turbine System Test Benches
IFAC World Congress, 2017

- Emulation of the realistic dynamic of the Wind Turbine
- Model Predictive Control
  - Optimization of the actuating variable based on predicted system behavior and reference trajectory
  - Internal model of the wind turbine on the system test bench
- Kalman Filter
  - Observation and correction of the system states
- Aeroelastic torque from aeroelastic model
  - Blade Element Momentum Theory

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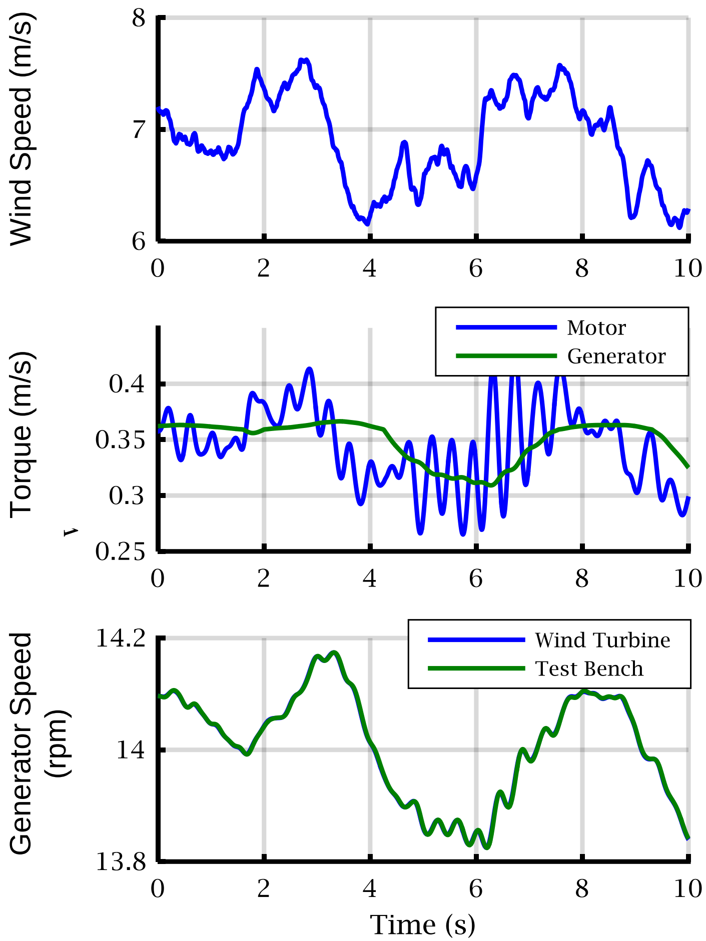
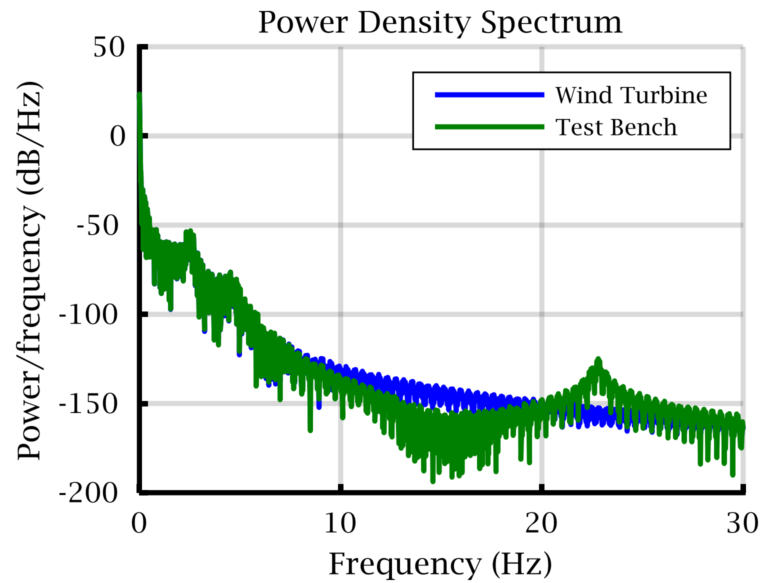
Inertia Eigenfrequency Emulation

Validation in simulation





- Very good reproduction of the realistic dynamic of the Wind Turbine as far as $f = 9\ \mathrm{Hz}$
- Experimental validation in the next months
- Parallel development of different methods
  - MPC
  - H_{inf}

Agenda

Conclusion

- Experiment teaches more than any simulation can do!
  - Looking forward to the next operation phase
- Drive train damping required

- Further development of the MHIL system
- Implementation of the MHIL system on different
  - System Test Benches
  - Wind Turbines
- Validation in Multi-Body Simulation

- Evaluation of
  - Certification on the System Test Bench
  - Validation of load reduction methods on the system test bench

Thank you very much for your attention!

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