CWD Center for Wind Power Drives

E.ON Energy Research Center

Commissioning of the 4 MW Testing Facility for Wind Power Drives at RWTH Aachen University

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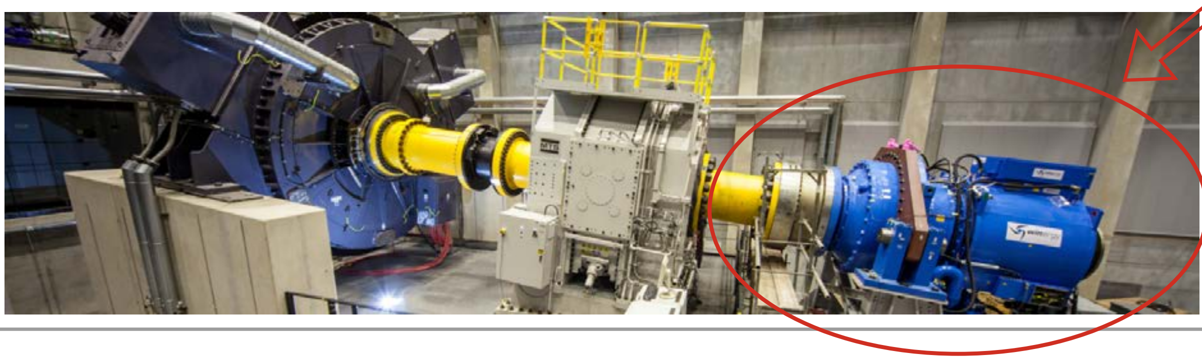
RWTH AACHEN UNIVERSITY

Motivation

- Investigation of wind turbine nacelles on a test bench exploiting:
  - Power Hardware in the Loop (PHIL) testing
  - Multi-Physics PHIL setup
  - System-Level testing environment
- Consideration of entire system up to limits of mutual component interactions



Outline

- Introduction
- System Level Nacelle Testing
- Test Setups and Results
- Conclusion

Center for Wind Power Drives

Aerodynamics, Control, Electrical and Mechanical Engineering combined in one Center

Directorate: Abel, Brecher, De Doncker, Hameyer, Monti, Jacobs, Schröder

CTO: Schelenz

Research Advisory Board: Industrial Companies

Prof. Abel	Controls
Prof. Brecher	Gears
Prof. De Doncker	Power Electronics
Prof. Hameyer	Generators
Prof. Monti	Grids
Prof. Schröder	Aerodynamics
Prof. Stich	Logistics
Prof. Jacobs – Chair for Wind Power Drives	Systemdesign & Test

E.ON Energy Research Center

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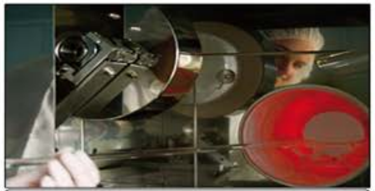
- Since June 2006: Largest research co-operation in Europe between a private company and a university
- Five professorships in the field of energy technology across 4 faculties
- Research areas: energy savings, efficiency and sustainable power sources

ACS Institute for Automation of Complex Power Systems

EBC Institute for Energy Efficient Buildings and Indoor Climate

FCN Institute for Future Energy Consumer Needs and Behavior

GGE Institute for Applied Geophysics and Geothermal Energy



PGS Institute for Power Generation and Storage Systems

Electrical Engineering & Information Technology | Mechanical Engineering | Business and Economics | Georesources & Materials Engineering

Institute ACS
Research Areas

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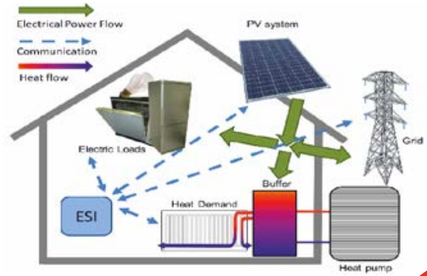


Applications

Smart Cities
Future Energy Networks
Center for Wind Drives
Future Internet

Grid Operations

Fundamentals of Grid Dynamics
Network Stability
Hybrid DC/AC Networks
Grid Monitoring
Grid Automation
Integration of Renewables

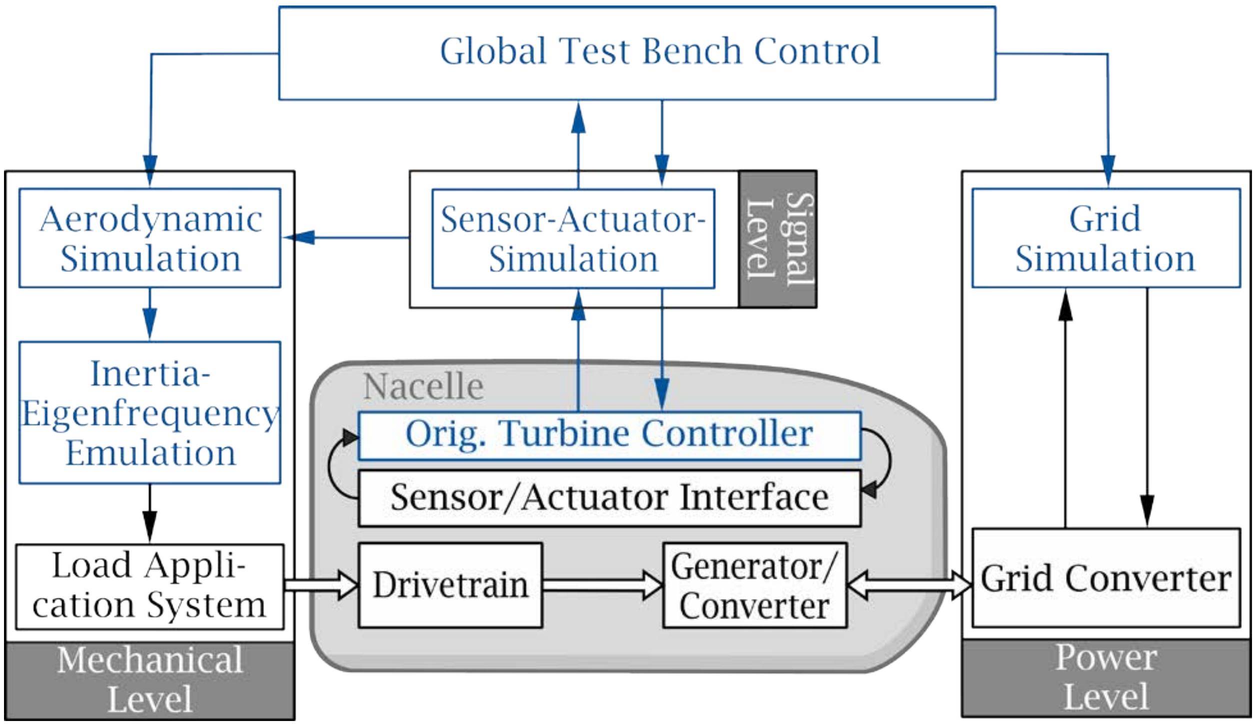
ICT 4 Energy

Energy as data-driven systems
Distributed Computing for
Complex System Simulation
Distributed Intelligence for
Energy Systems
Cloud applications for energy
Real-Time Systems

System-Level Nacelle Testing

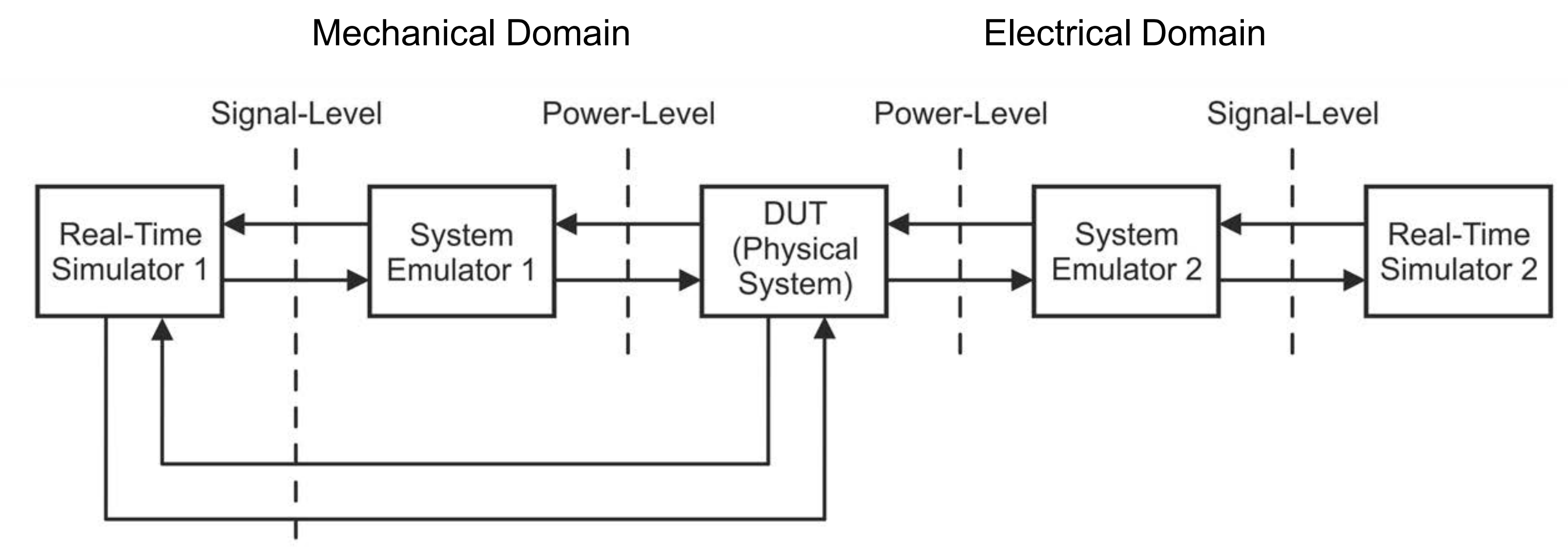
- System-Level Multi-Physics Power Hardware in the Loop testing emulates:
  - Forces and moments at rotor hub
  - Voltages at the power grid connection
  - Sensor interfaces

- Advantages of approach:
  - Deterministic
  - Repeatable
  - Time-invariant
  - High-load capable



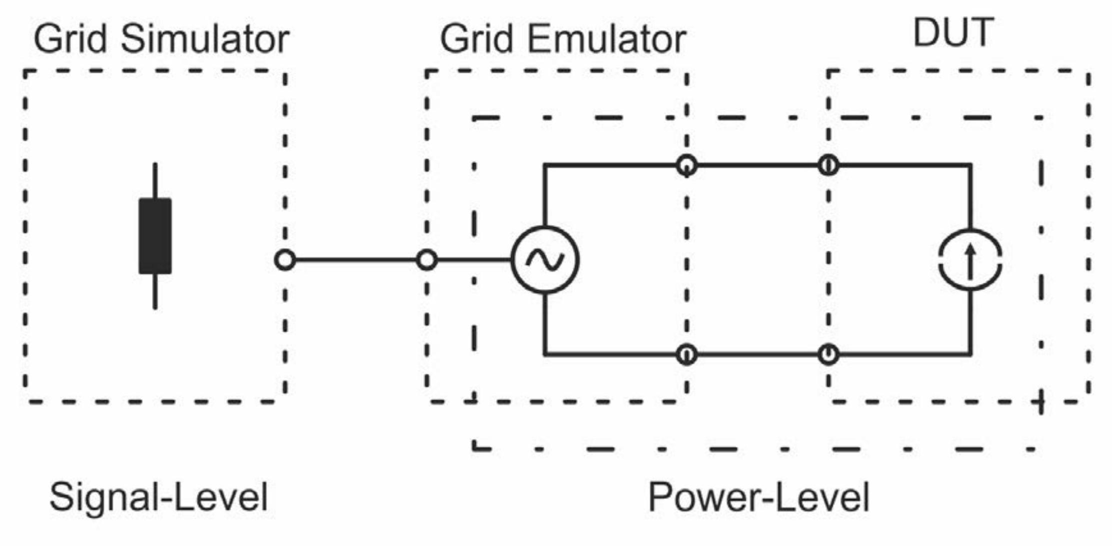
Multi-Physics
Power Hardware in the Loop

- Simulation environments of the interfaces depend on physical domain:
  - Electrical domain: *Simulator:* RTDS *Time Step:* 50 µs
  - Mechanical domain: *Simulator:* dSPACE *Time Step:* 10 ms
  - Signal-level domain: *Simulator:* dSPACE *Time Step:* 10 ms



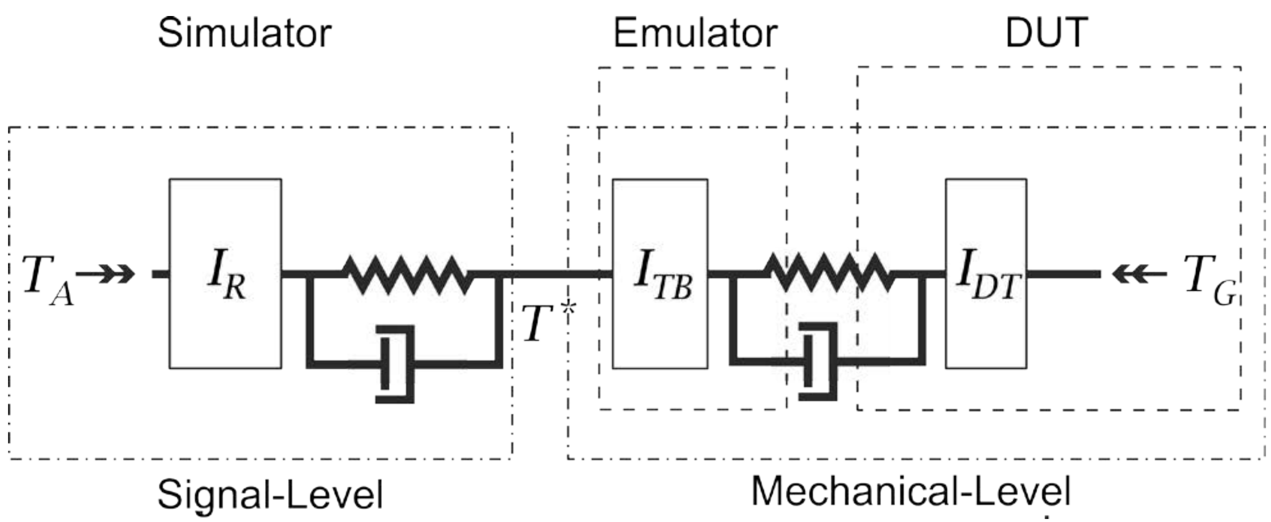
Emulator Interface

- Mapping of simulation results from signal-level to power-level
- Enforcing the conservation of energy at the physical connection terminals

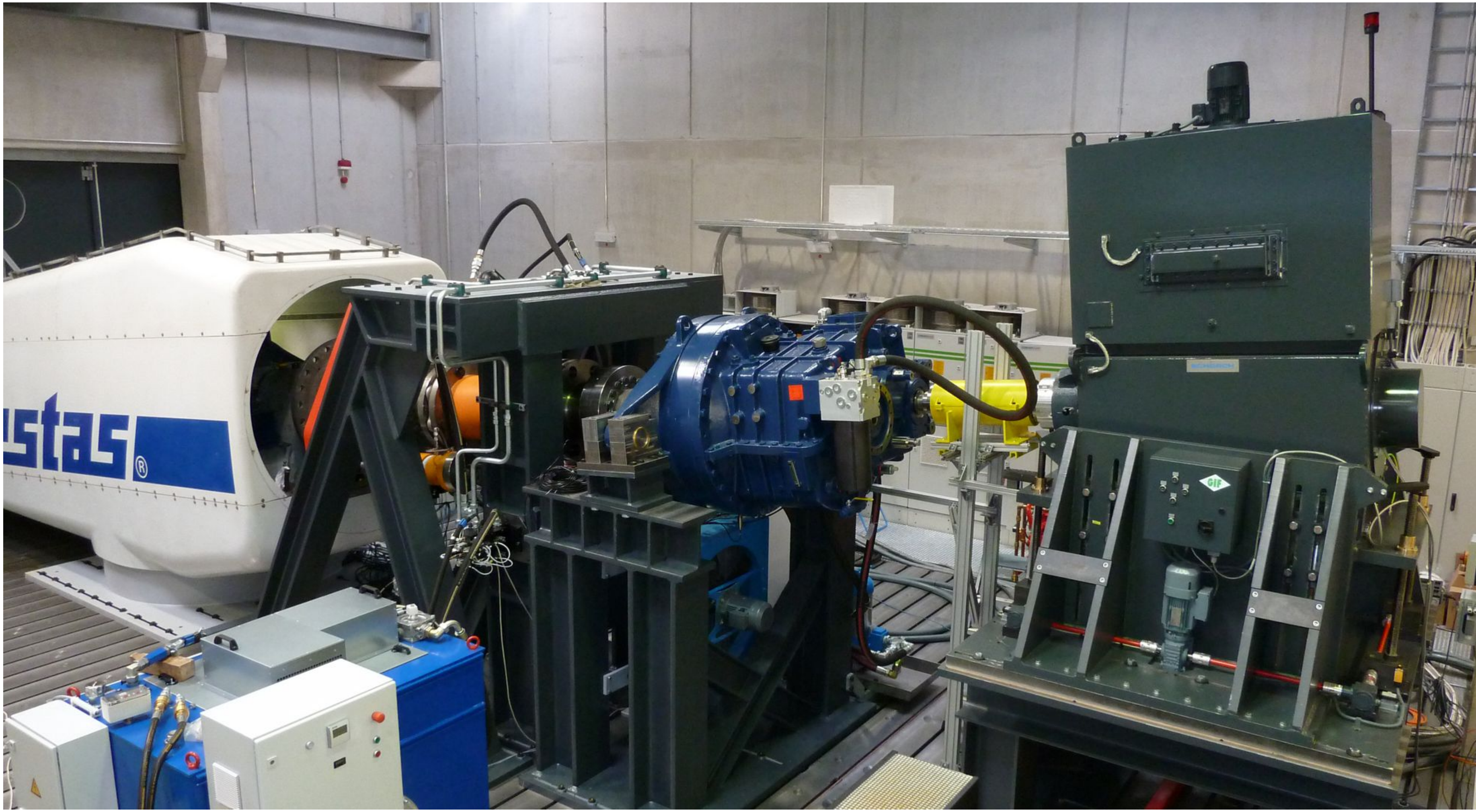


Emulator Interface

- Mapping of simulation results from signal-level to power-level
- Enforcing the conservation of energy at the physical connection terminals
- Equivalent mechanical-level interface (Rotational)

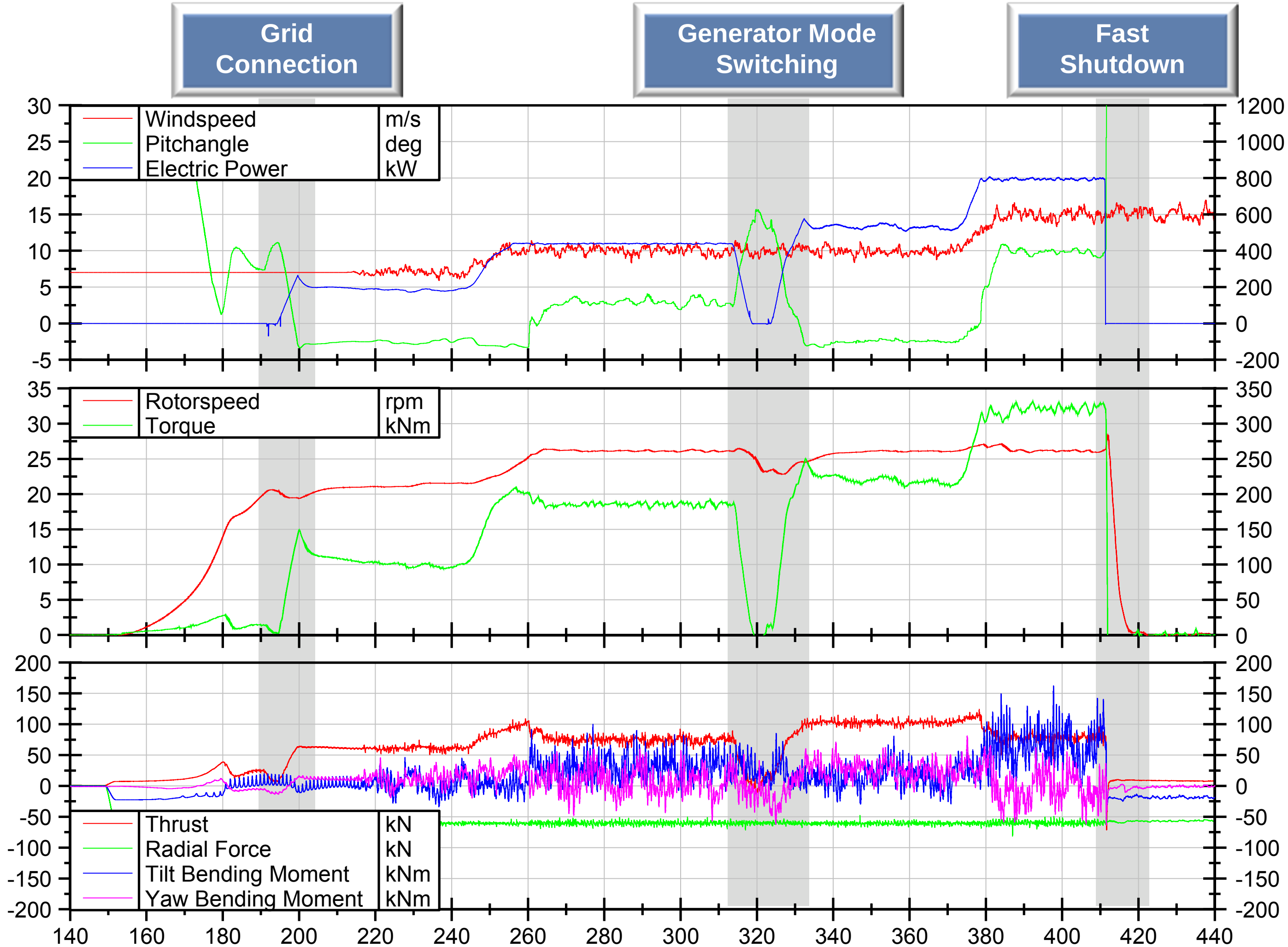


1 MW Setup



1 MW Test Bench Results

Test campaign with original wind turbine controller on the 1 MW test bench demonstrator in HIL operating mode



4 MW Setup

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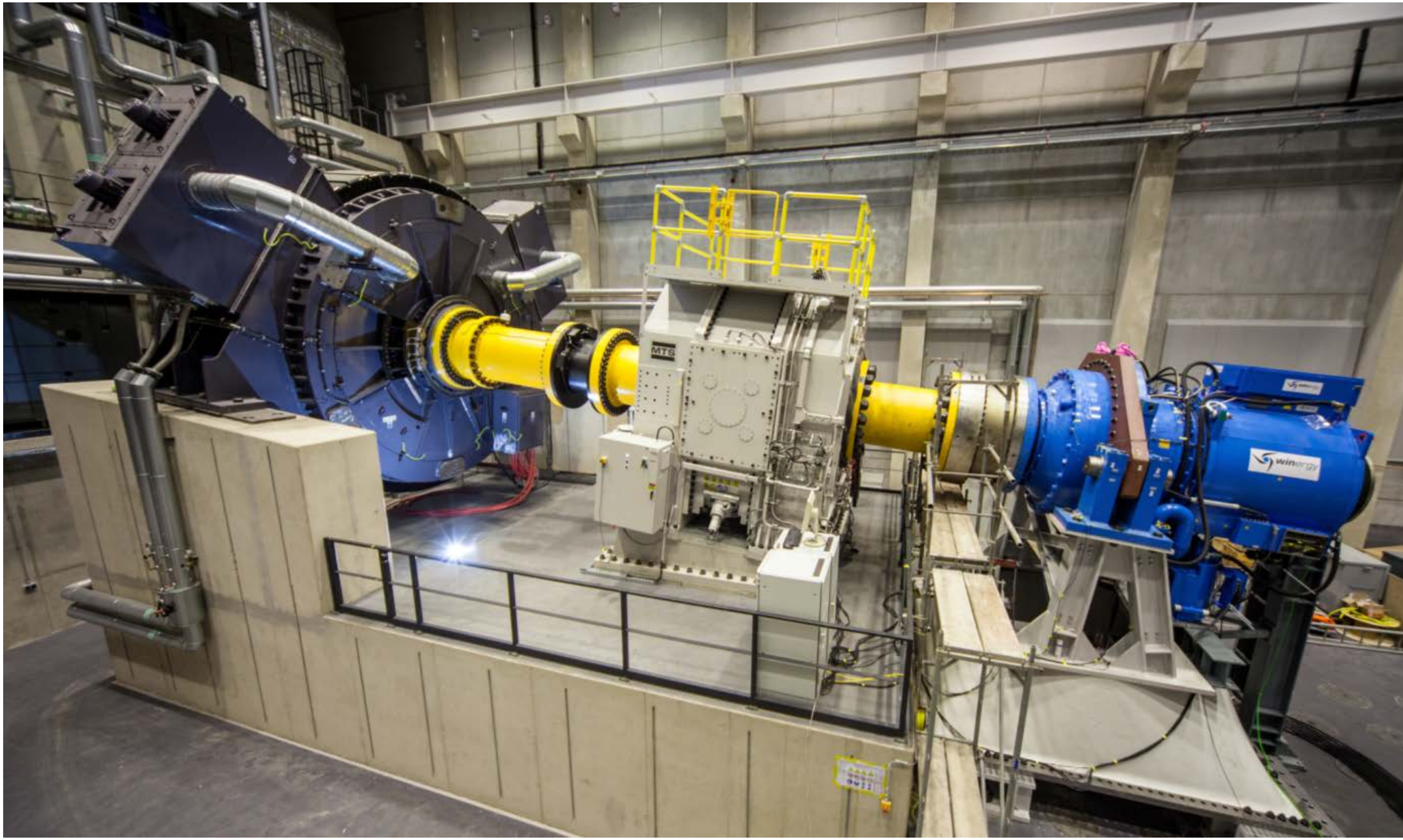
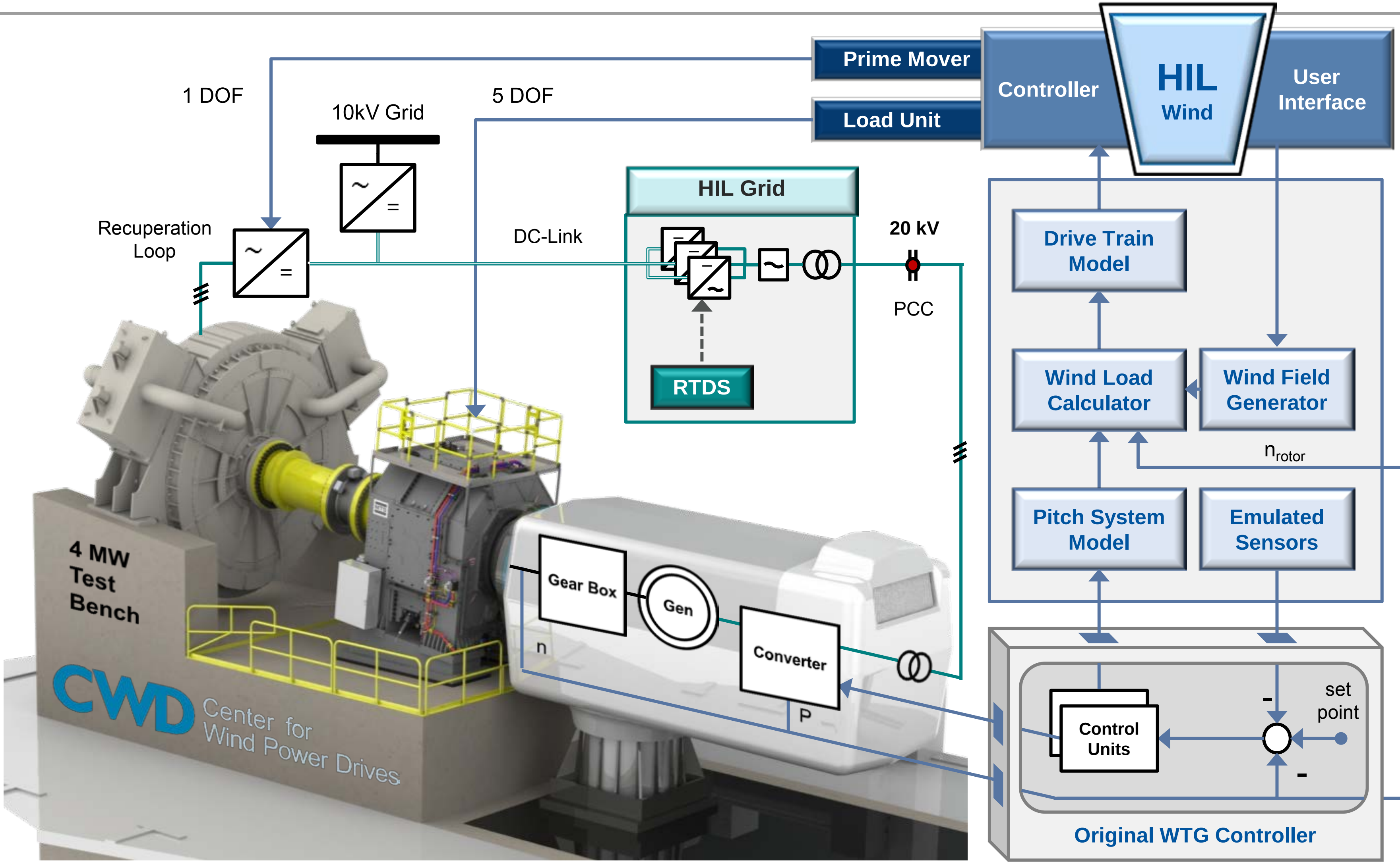
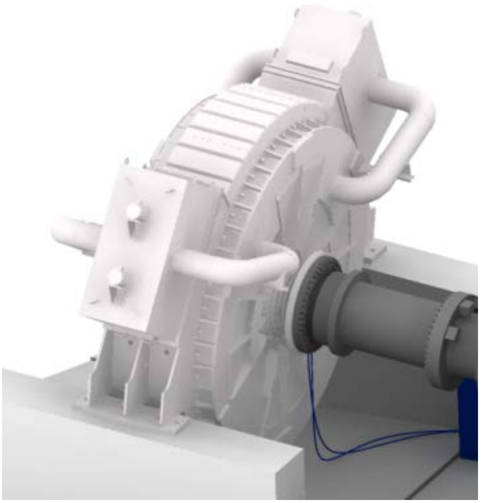
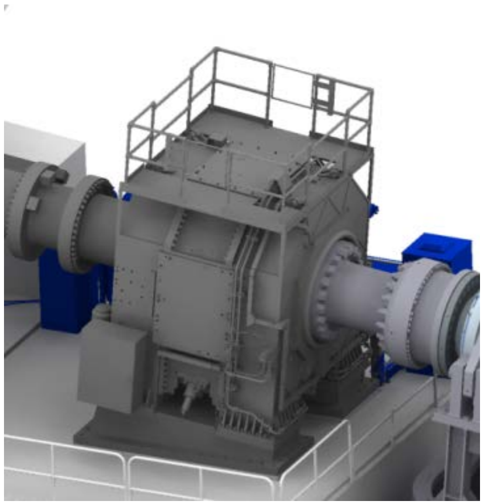


4 MW Test Bench Overview



Mechanical Load Application



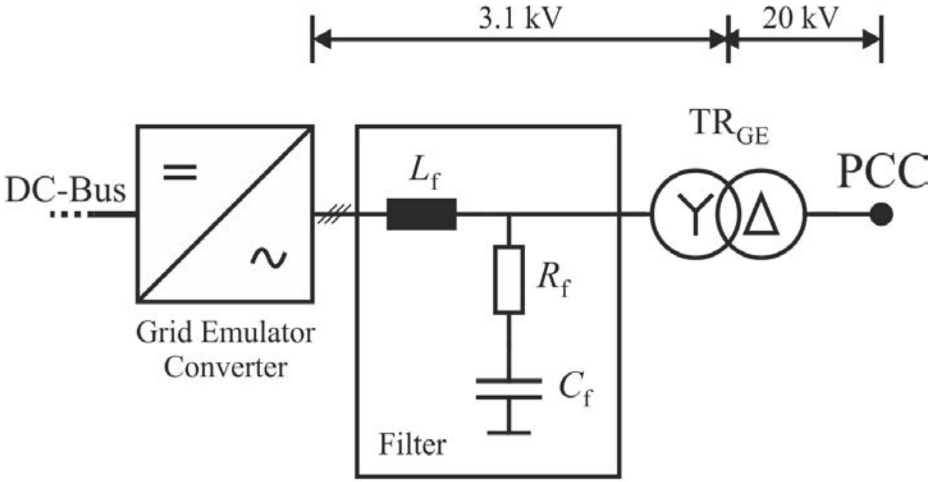


- **PMSG Direct Drive**
  - Power: P_n = 4000 kW
  - Speed: n_{max} = 30 rpm
  - Torque: T_n = 2,7 MNm

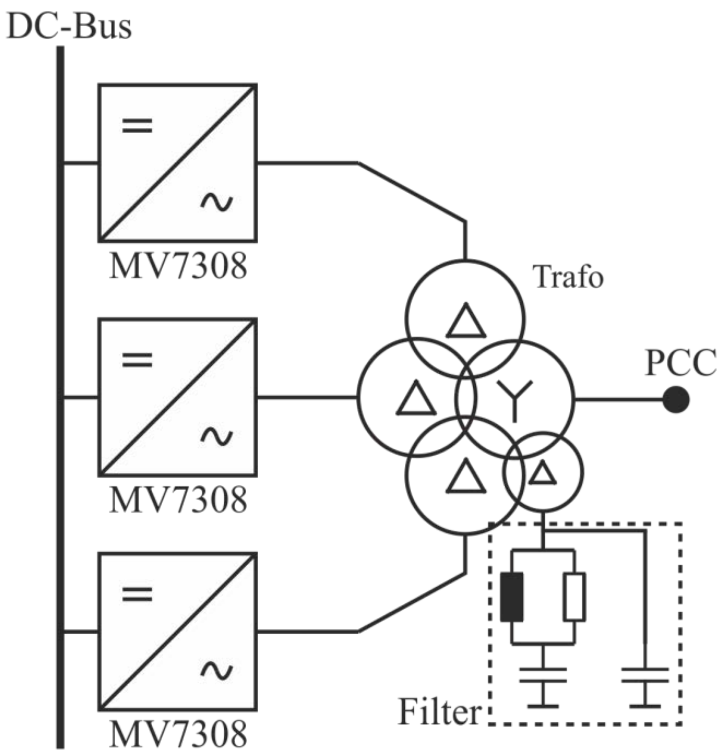
- **Wind Load Simulator**
  - 5 DOF load application system
  - Force capacity: ~ 3 MN
  - Bending moment capacity: ~ 7 MNm

Electrical Load Application

- *Stage 1*
  - Power: 8 MVA
  - Currently extended to stage 2

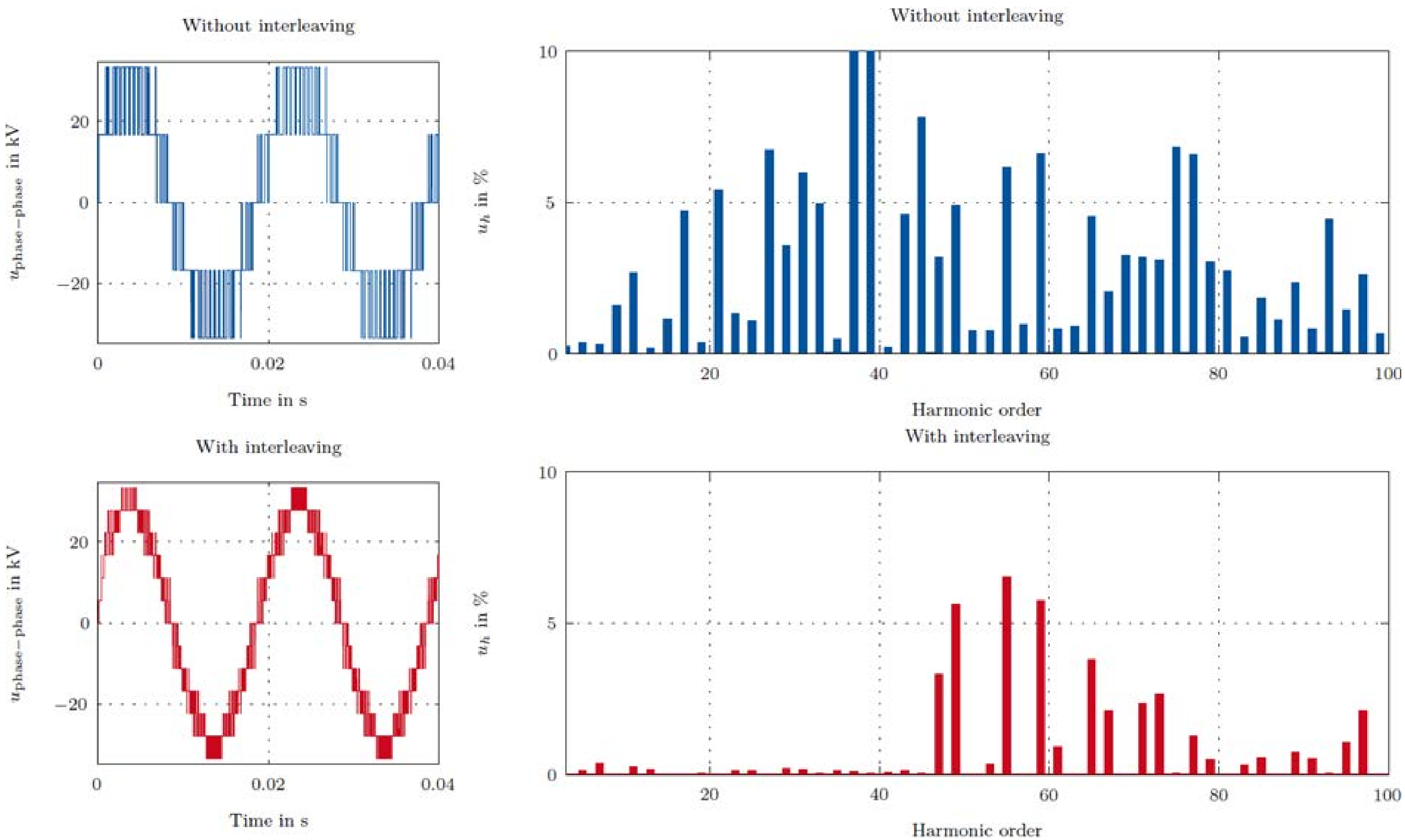


- *Stage 2:*
  - Power: 24 MVA
  - Interleaved switching



Simulation of Grid Emulator

- Simulated voltages at PCC



Simulation Mechanical Emulation

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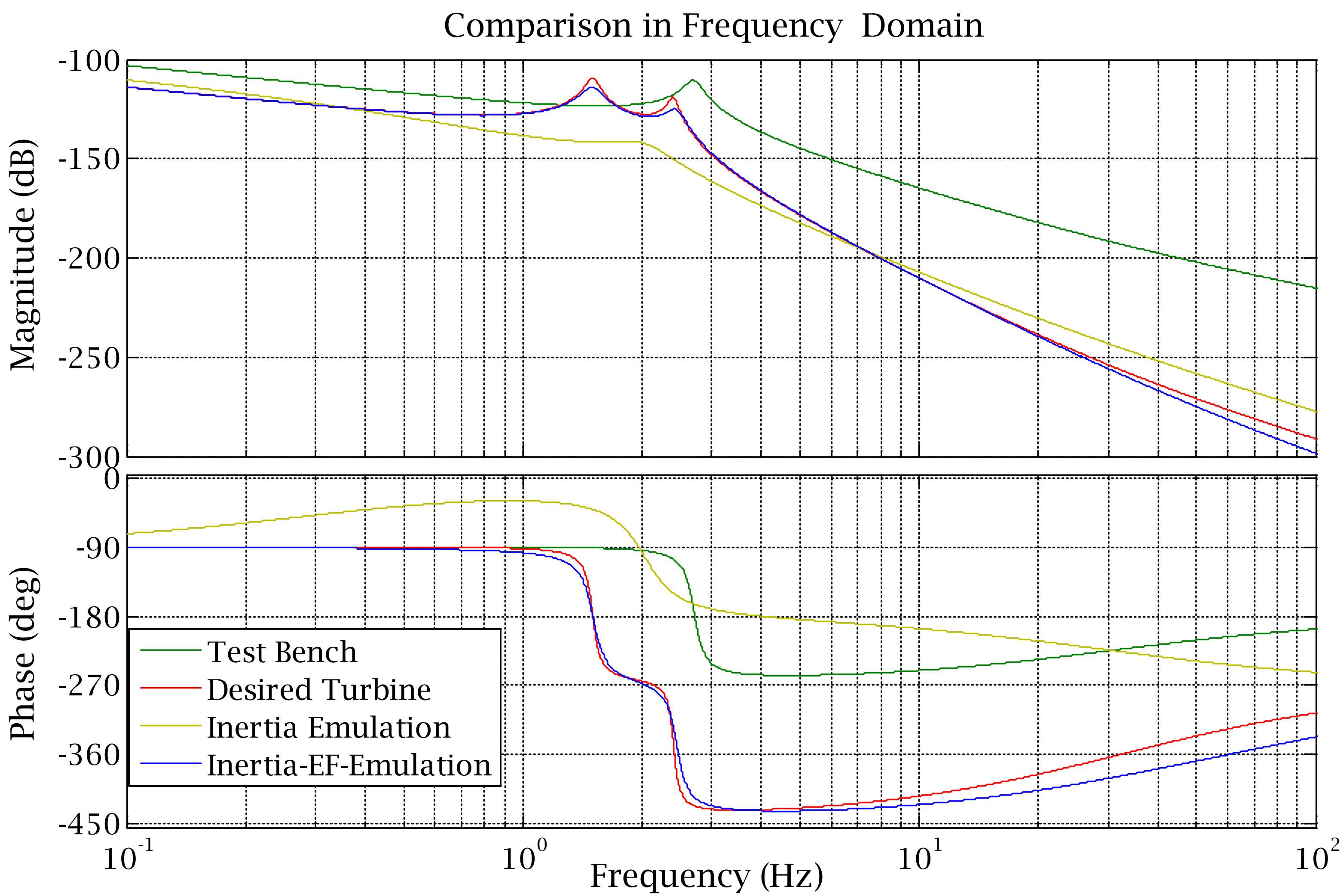
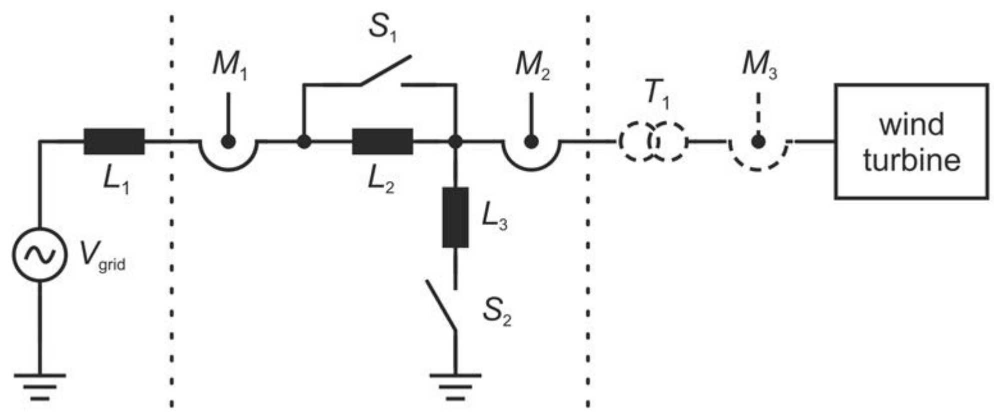
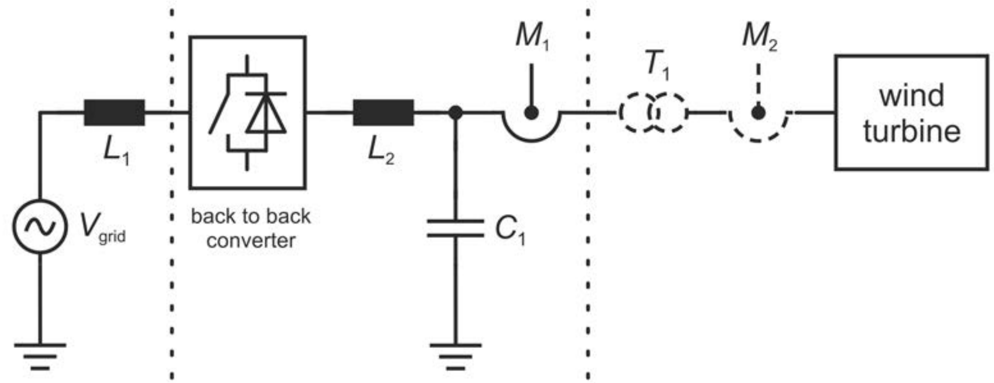


Fault Ride Through Testing

- FRT-Converter advantages:
  - Generation of arbitrary voltage behavior up to limits of converter setup
  - In case of test bench testing:
    - Extension of existing setup
  - Possible use for PHIL



FRT-Container setup



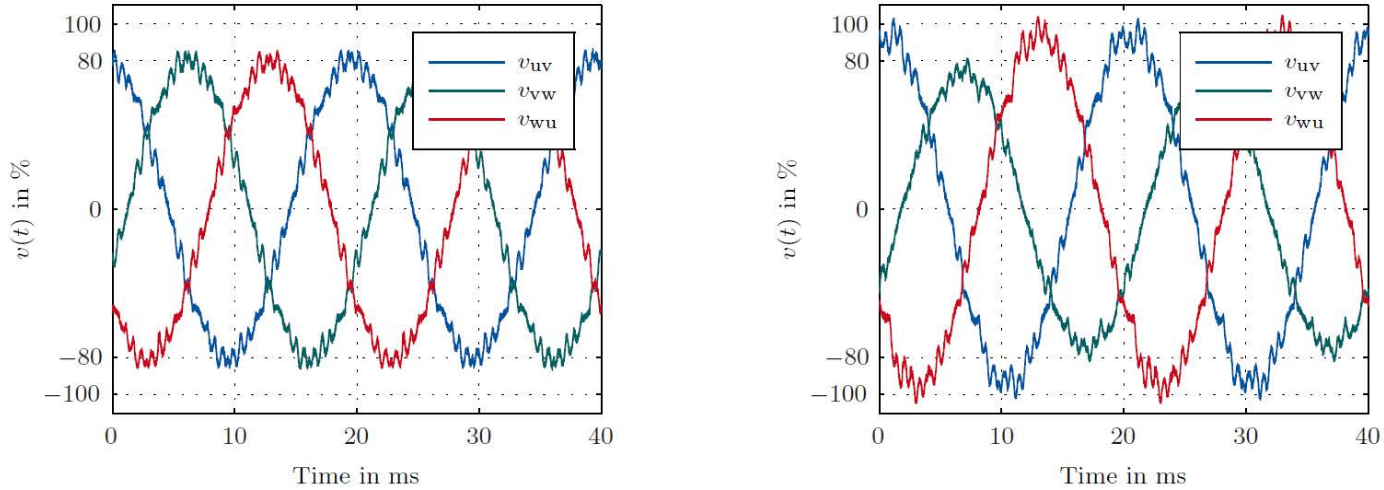
FRT-Converter setup

Rating of Test Benches

Comparison of 1-MW and 4-MW test benches

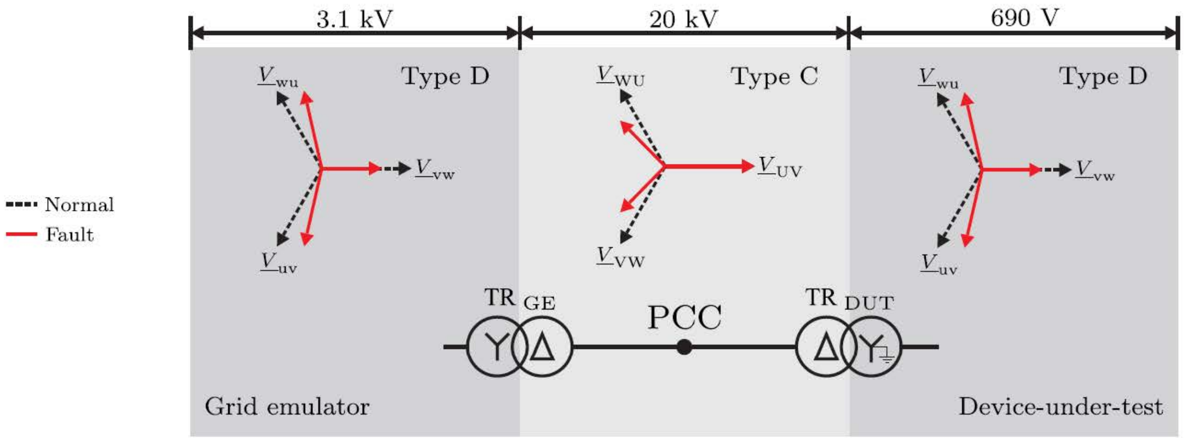
	Power	1 MW	4 MW
Electric Motor	Torque	395 kNm	2.7 MNm
	Speed	29 rpm	30 rpm
Load Application System	Thrust	480 kN	4 MN
	Pitch Moment	168 kNm	7.2 MNm
	Yaw Moment	194 kNm	7.2 MNm
	Vertical Force	200 kN	3.25 MN
	Horizontal Force	–	3.25 MN
Power Converter System	Total Power	2.5 MVA	8 MVA (each, 24 MVA total)
	Switching Frequency	2.5 kHz	1 kHz (each, interleaved)
	Parallel Converters	4	3

4 MW Test Bench Stage 1



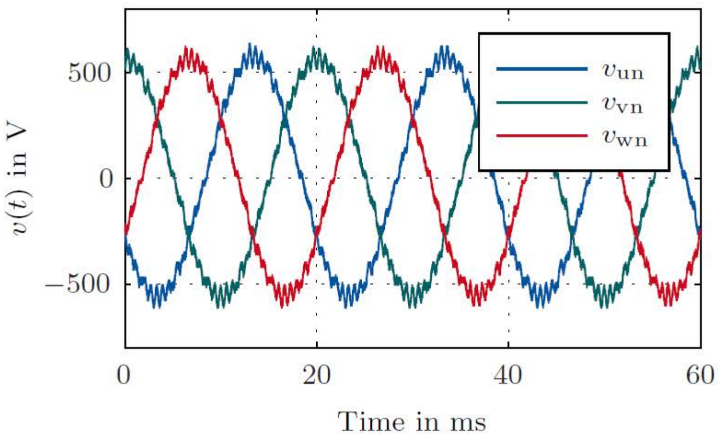
(a) Symmetrical fault (b) Unsymmetrical fault

Emulated grid faults

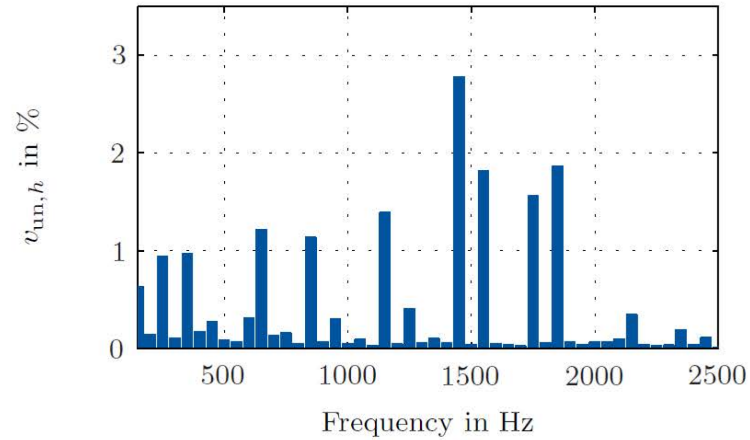


Propagation of fault-voltage waveform in the test bench

DUT Behavior

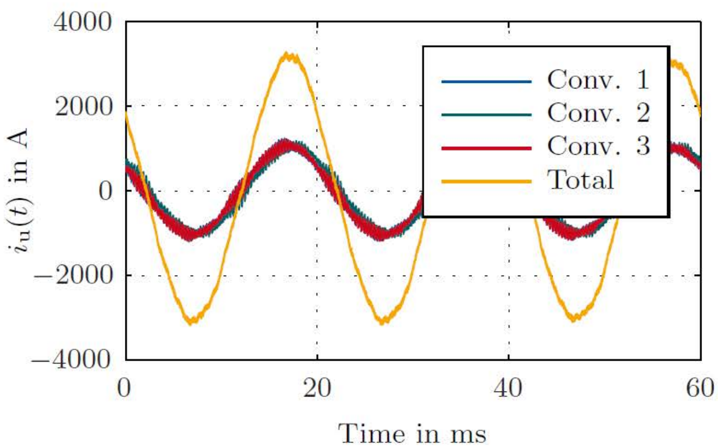


(a) Instantaneous waveform

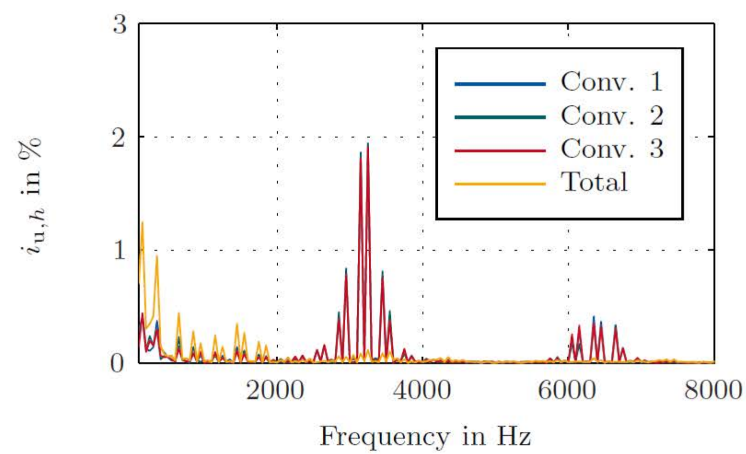


(b) Frequency spectrum

Measured emulated grid-voltage



(a) Instantaneous waveform



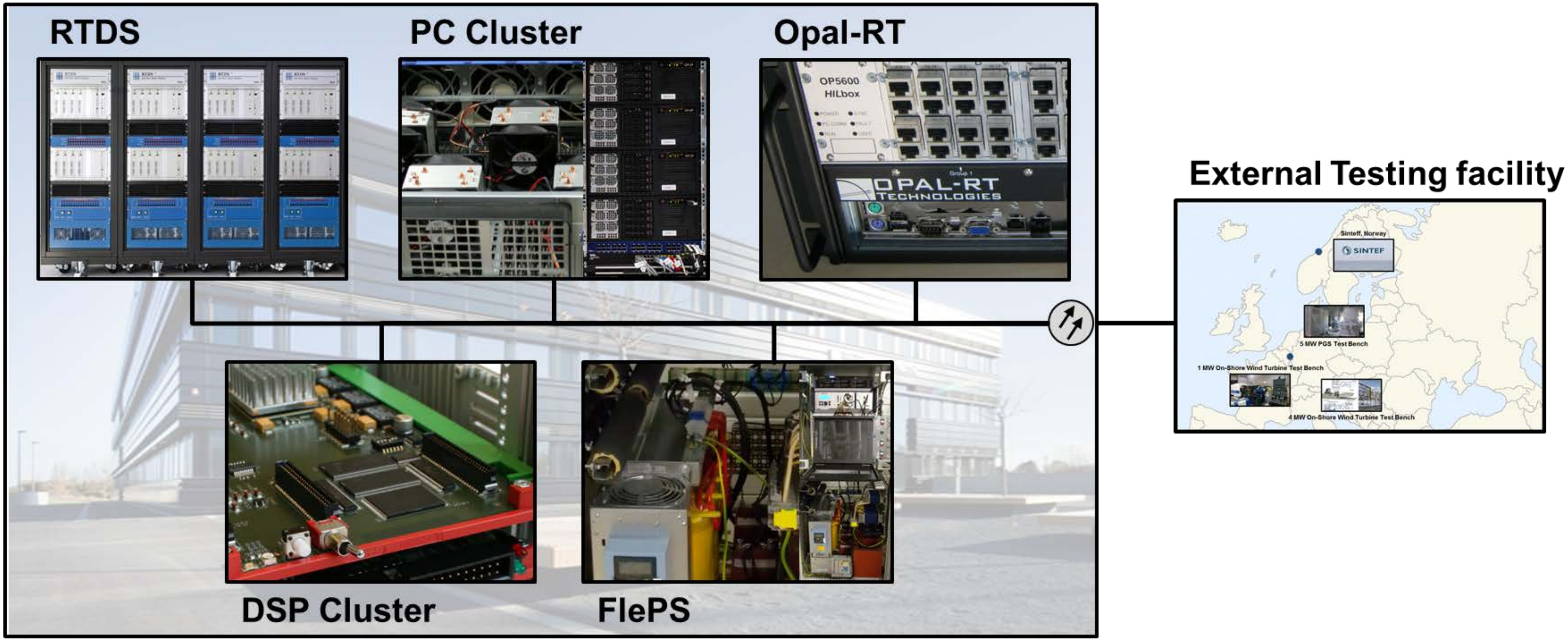
(b) Frequency spectrum

Conclusion

- Concept of System-Level Multi-Physics Power Hardware in the Loop test bench for wind turbine nacelles has successfully been realized
- Interactions between electrical and mechanical side have been shown
- Wind turbine fully in operation with original controller on 1 MW test bench
- Stage 2 of 4 MW test bench fully in operation spring 2015

Thank you very much for you attention!

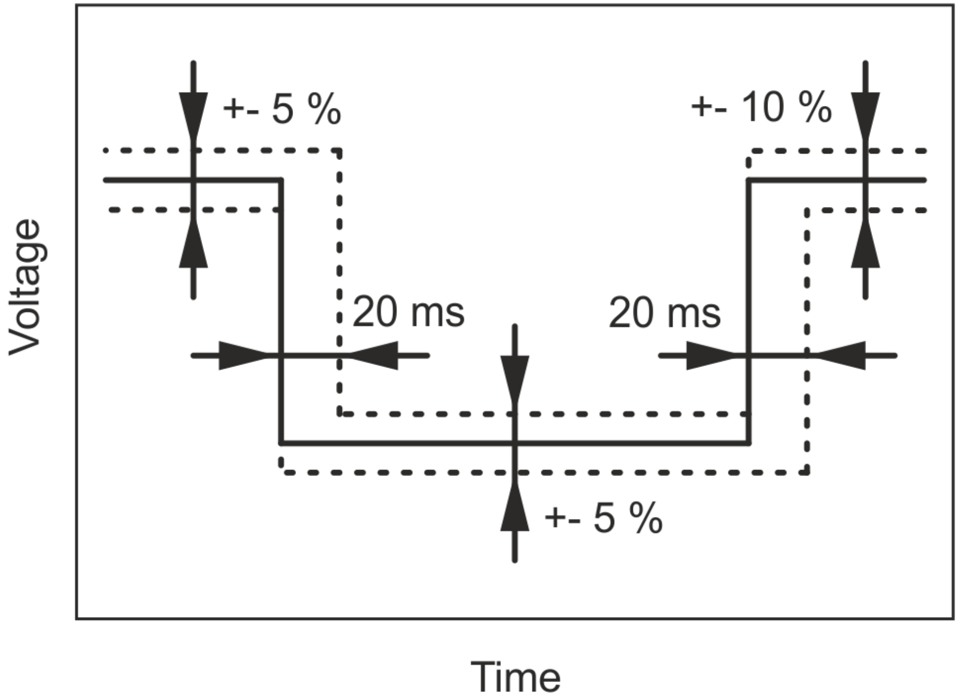
Real Time Laboratory at ACS



Fault Ride Through Certification

FRT testing demands conform to FGW TR3 (based on [3])

Test Nr.	Fault Depth (V/V_0)	Fault Duration (ms)
1	≤ 0.05	≥ 150
2	0.20 – 0.25	≥ 550
3	0.45 – 0.55	≥ 950
4	0.70 – 0.80	≥ 1400



Tolerance of the FRT voltage sag according to IEC 61400-21 (based on [7])

Inertia Emulation – Done wrong