10.11.2022
6th International Workshop on Grid Simulator Testing of Wind Turbine Power Trains and Other Renewable Technologies

PQ4Wind Project

Pathway to novel large scale grid integration process

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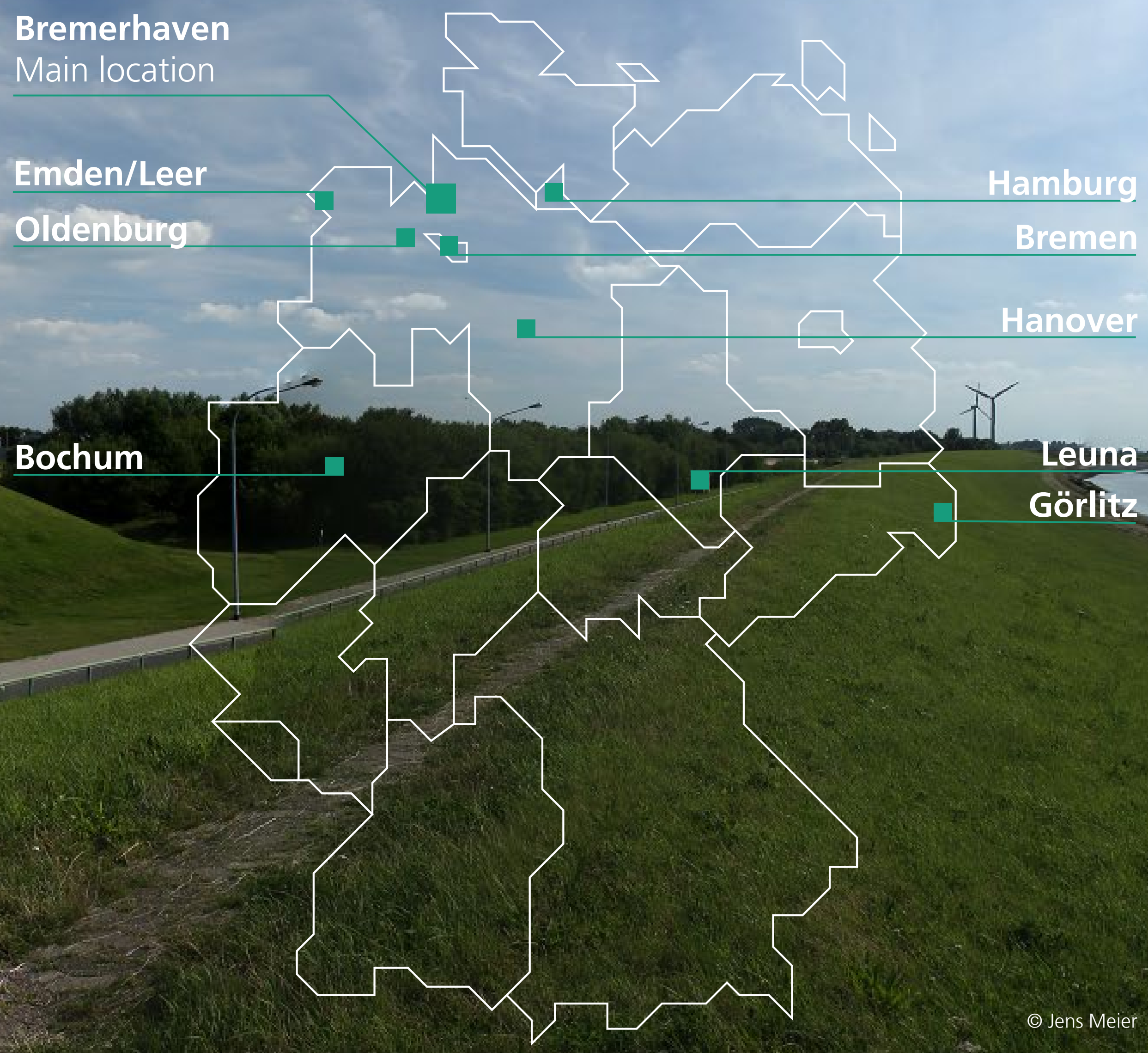

- 300 staff
- 90 publicly funded research projects
- € 38 m operating budget / year 2021
- € 96 m investment in test infrastructure

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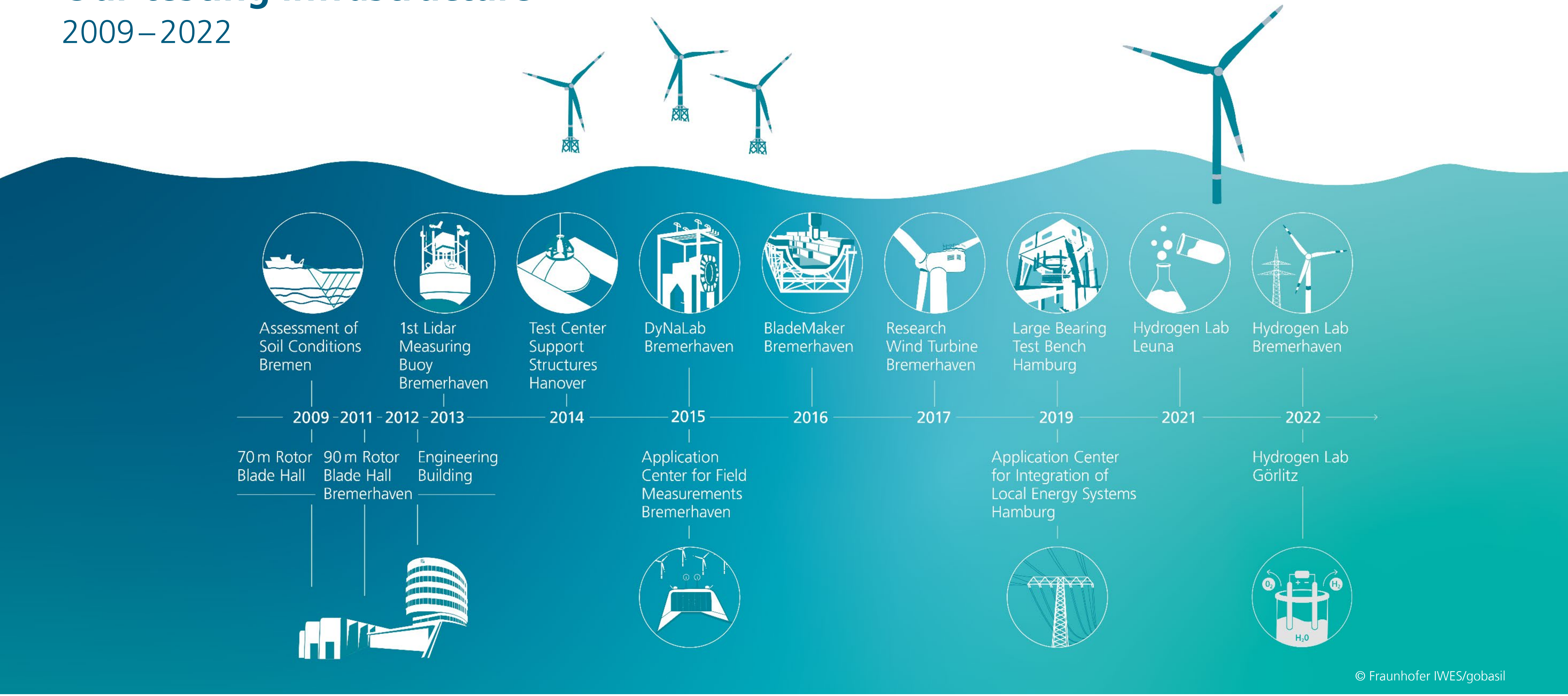
Our testing infrastructure

2009 – 2022



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Research and service spectrum of IWES

Test infrastructure

Digitalization

Offshore

Hydrogen

Grid integration testing of wind turbines, subcomponents and components on test benches

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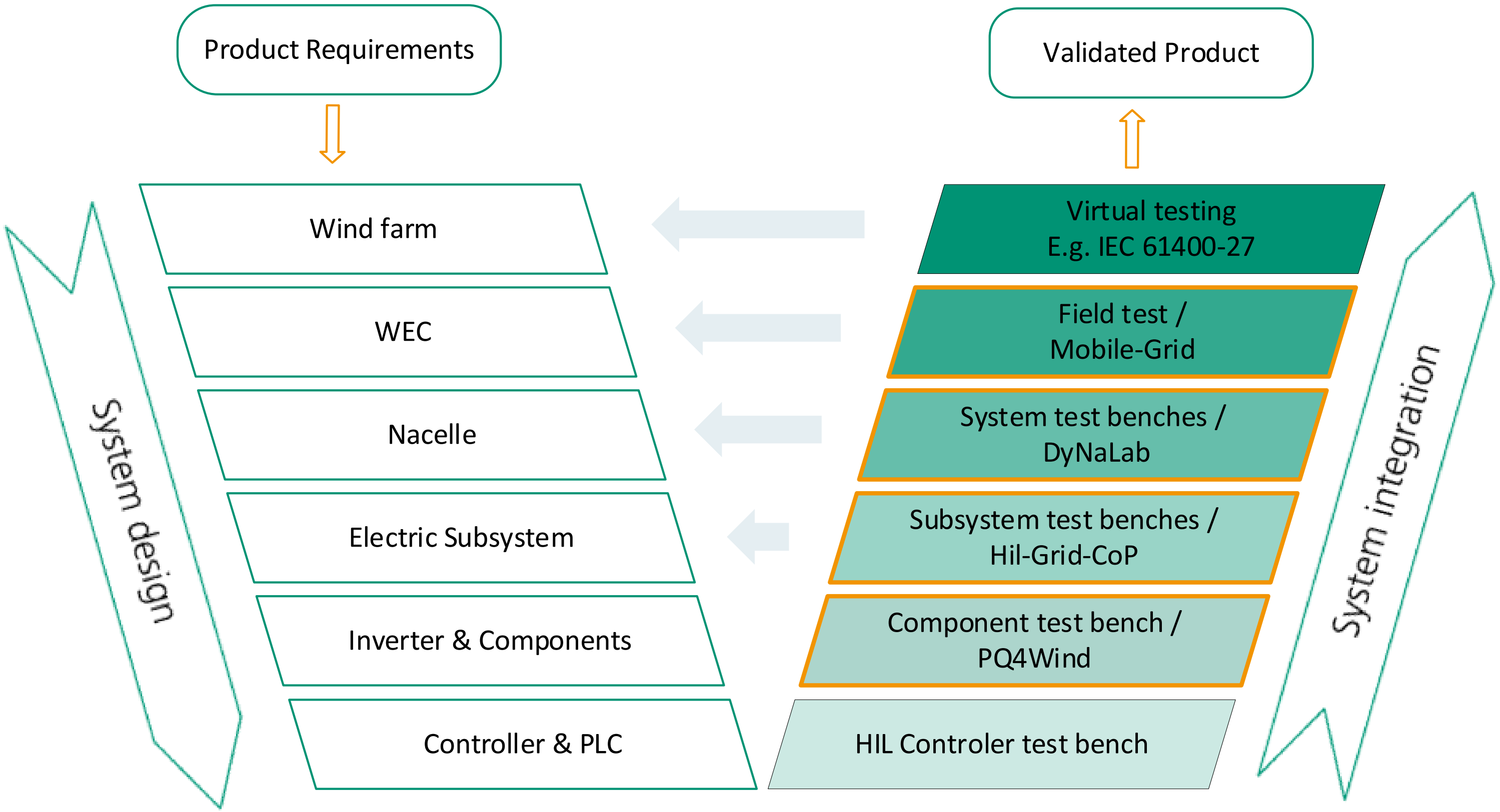
What will be the future of grid integration testing

Grid code testing >> enabled by different test benches worldwide



- Baseline of requirements are provided in grid codes
- Additional requirements
  - Grid forming behavior
  - Requirement for different model type
- Interaction studies for risk mitigation - systems complexity
- Installation approval for PPMs will be granted after conducting interaction studies

Interaction studies in power systems

	Multi- Infeed and interaction studies - Interaction between at least two power electronic devices					
Type	Control loop interaction		Interaction due to non linear characteristics		Harmonic and Resonance interaction	
	Slow control (steady state)	Dynamic control	AC fault performance	Transient stress and nonlinear effects	Sub-synchronous resonance	Harmonic emission and resonance
Phenomena	AC Filter hunting Voltage control Conflicts P/V stability	Power oscillation Control loop interaction Sub-synchronous control interaction Voltage stability	Commutation failure Voltage distortion Phase imbalance Fault recovery Protection performance	Load rejection Voltage phase shift Switching and change of network Transformer saturation Isolation coordination	Sub-synchrous torsional interaction	Resonance Harmonics Harmonic instabilities Core saturation stability
Means for assessment	Static Analysis RMS time domain	RMS time domain Small signal analysis EMT time domain	RMS time domain EMT time domain	EMT time domain	EMT time domain	Harmonic analysis Small signal analysis EMT time domain

Aaccording to: Cigré WG B4-81 and Expert Group Interaction Studies and Simulation Models (EG ISSM) – FINAL REPORT

Interaction studies Model Requirements of PPM

Based on ENTSOE expert group for upcoming RFG (European Network Code Requirements for Generators)

The impedance model of PPM

- At least in the range 5.0 Hz – 2.5 kHz;
- On request up to 9 kHz
- Positive and for the negative phase sequence

The EMT model of PPM

- Valid for frequency range 0.2 Hz – 2.5 kHz
- Valid for specified operating range and control modes
- Valid for balanced and unbalanced AC network faults
- Include the power plant level control and the power plant relevant functionalities
- Include lines and/or cables, PPM transformers including saturation, resistors, filters, breaker and AC arrester;
- Include protection function

Whats the value of studies without validated models

11/11/2022

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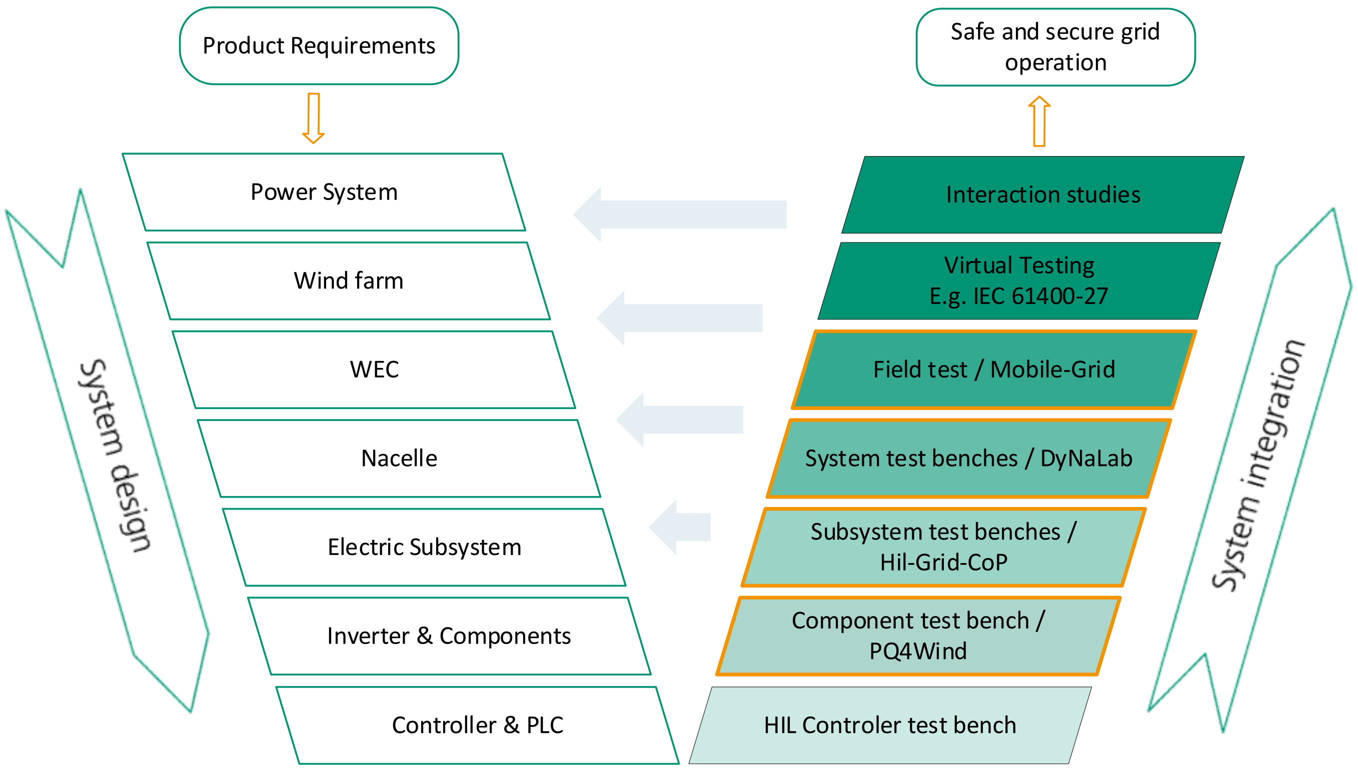
What will be the future of grid integration testing

Extension of V-Model



Actual discussion

- **Validated models are needed for interaction studies**
- **Gigantic system test benches**
  - 25 MW++ power range
  - Investment cost of approx. 80 Mio€
  - Monthly occupation rate of public funded test benches approx. 0.8 Mio€
- Long occupation due to logistics, variant testing, various markets will result in high costs and less test bench capacity
- Limited usage time due to enormous turbine grow
- Technical limits of actual grid emulators

Grid integration testing on large system test benches will not be the future

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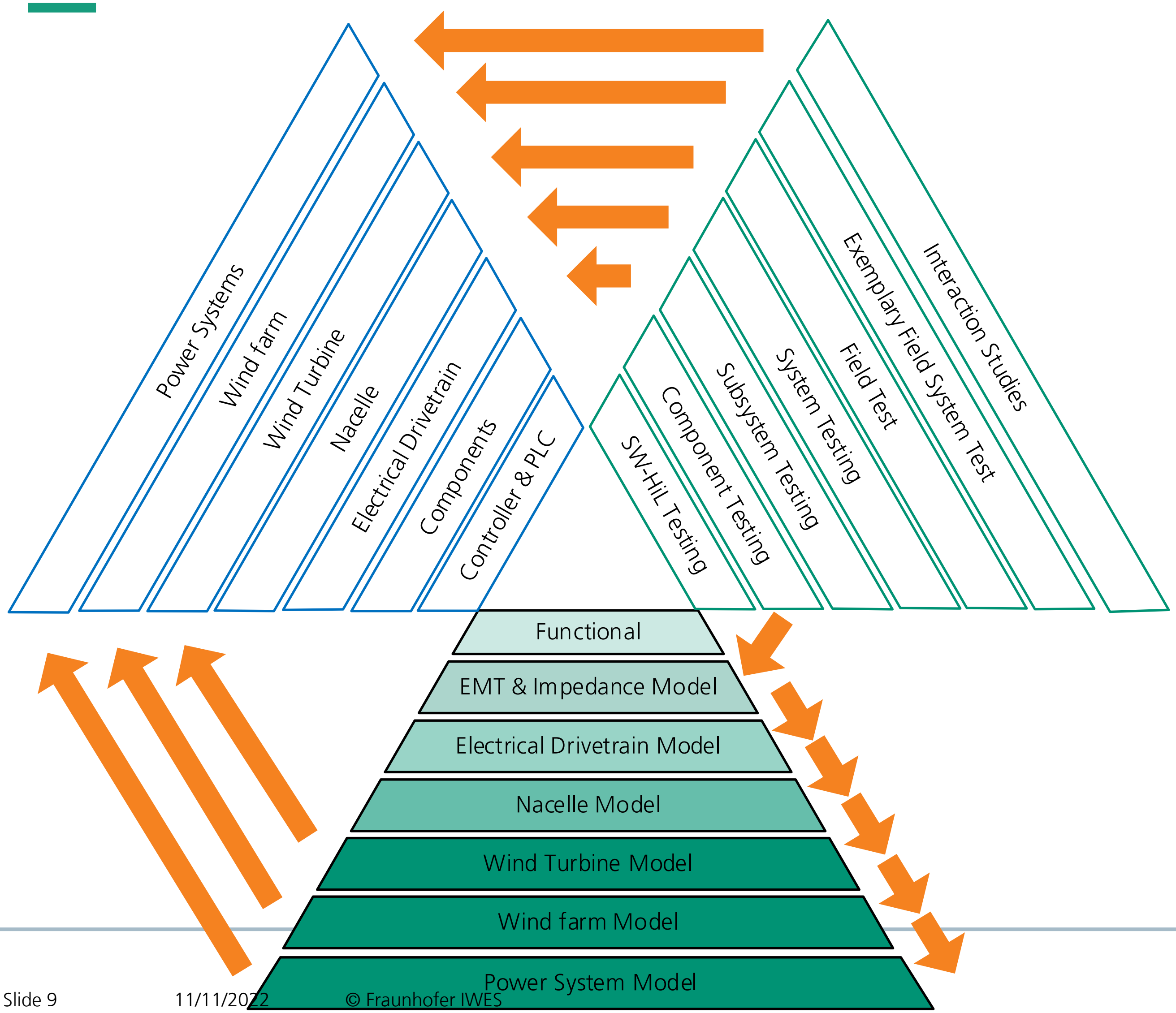
Component based certification/validation

Testing of entire wind turbines in sub-parts of individual components



- Two V-model branches: design validation and model validation
- Using optimized component test rigs (quite cheap compared to system test benches)
  - Run test for model (impedance and EMT) validation
  - Having full dynamic range under control
- Adding a third leg to V-Model
- Building up entire turbine models based on validated component models
- Building PPMs bases on turbine and power engineering components
- End-to-end model development > no aggregated models

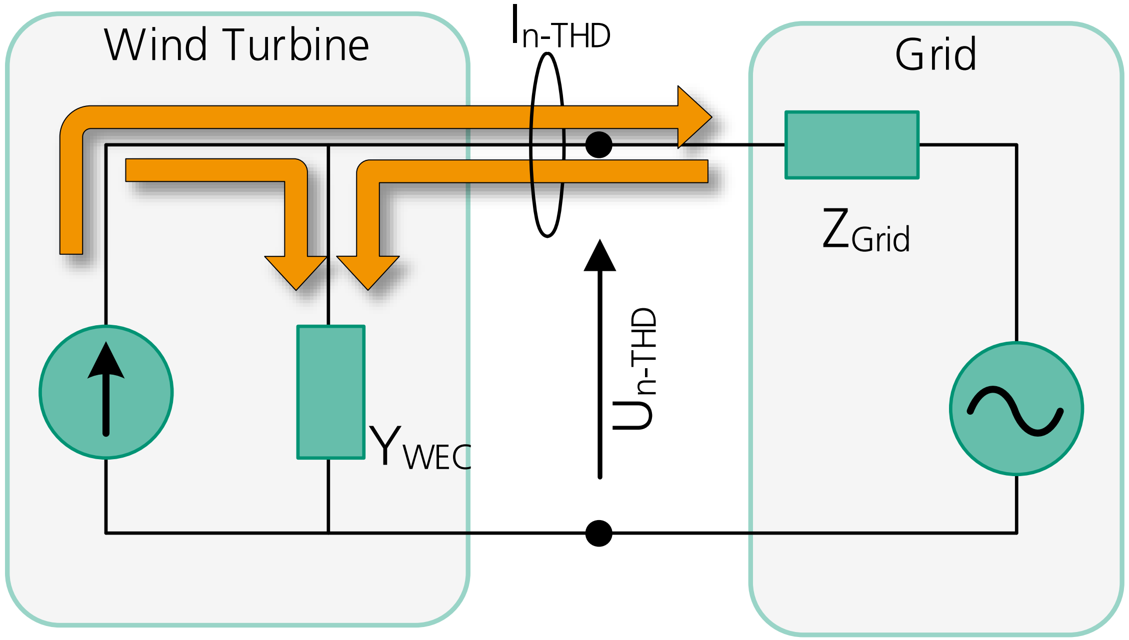
- **Ensure objective model validation**

PQ4Wind – Motivation

Generalized harmonic measurement and impedance characterization

- Harmonic measurement method in IEC is only valid for single measurement location
  - Unknow background noise
  - Unknow grid impedance
  - Unknow wind turbine
  - Single point measurement

- Testbench must control harmonics and impedance in a wide bandwidth
- Impedance validation by single ton harmonic injection



Using small signal impedance

Source: IWES

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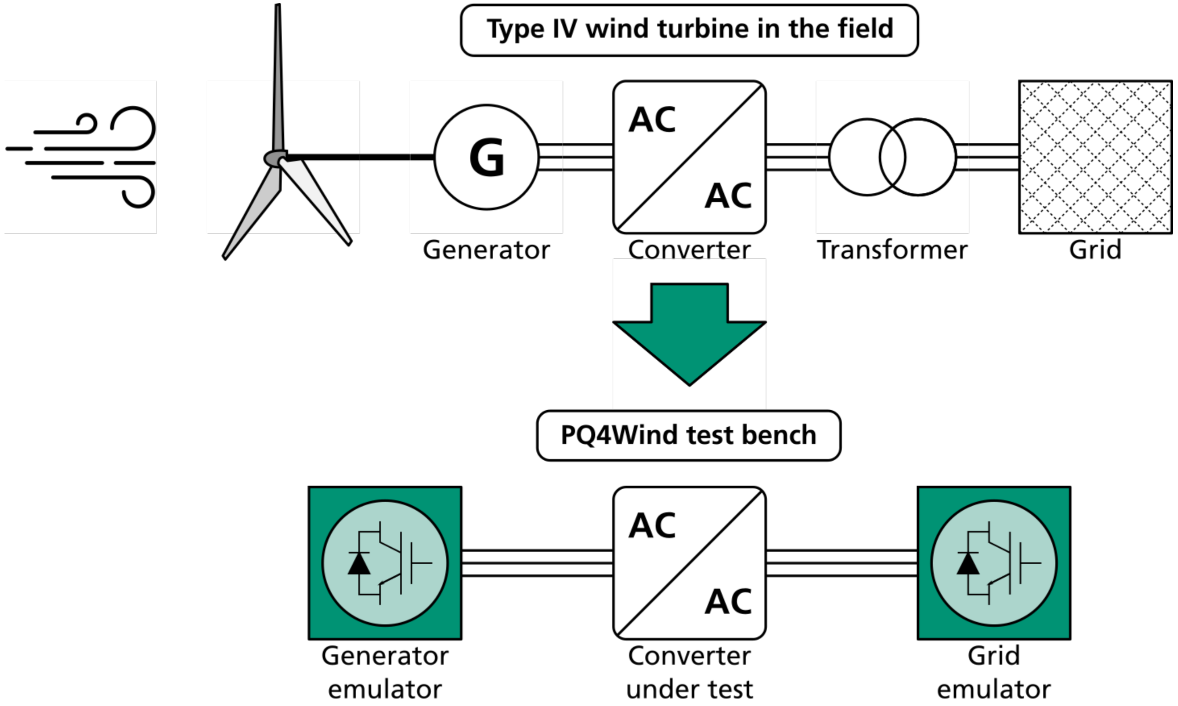
PQ4Wind - Testing bench – Keypoints

Testing on component level



PQ4Wind test bench	
Apparent specimen power	8 MVA
Phase-to-phase voltage	1050 V_{RMS}
Fundamental frequency	40-70 Hz
Total harmonic distortion	<< 1 % at 50 Hz
Cumulated switching frequency	128 kHz
Harmonic injection	Up to 10 kHz
Impedance emulation	Up to 10 kHz
Fault ride through capability	150 % HVRT at 690 V_{RMS} 0 % LVRT (ZVRT for max. 2 s)
Commercial availability	Q4 2023
Extendable	Site and modular design will allow doubling the specimen size

Source: IWES

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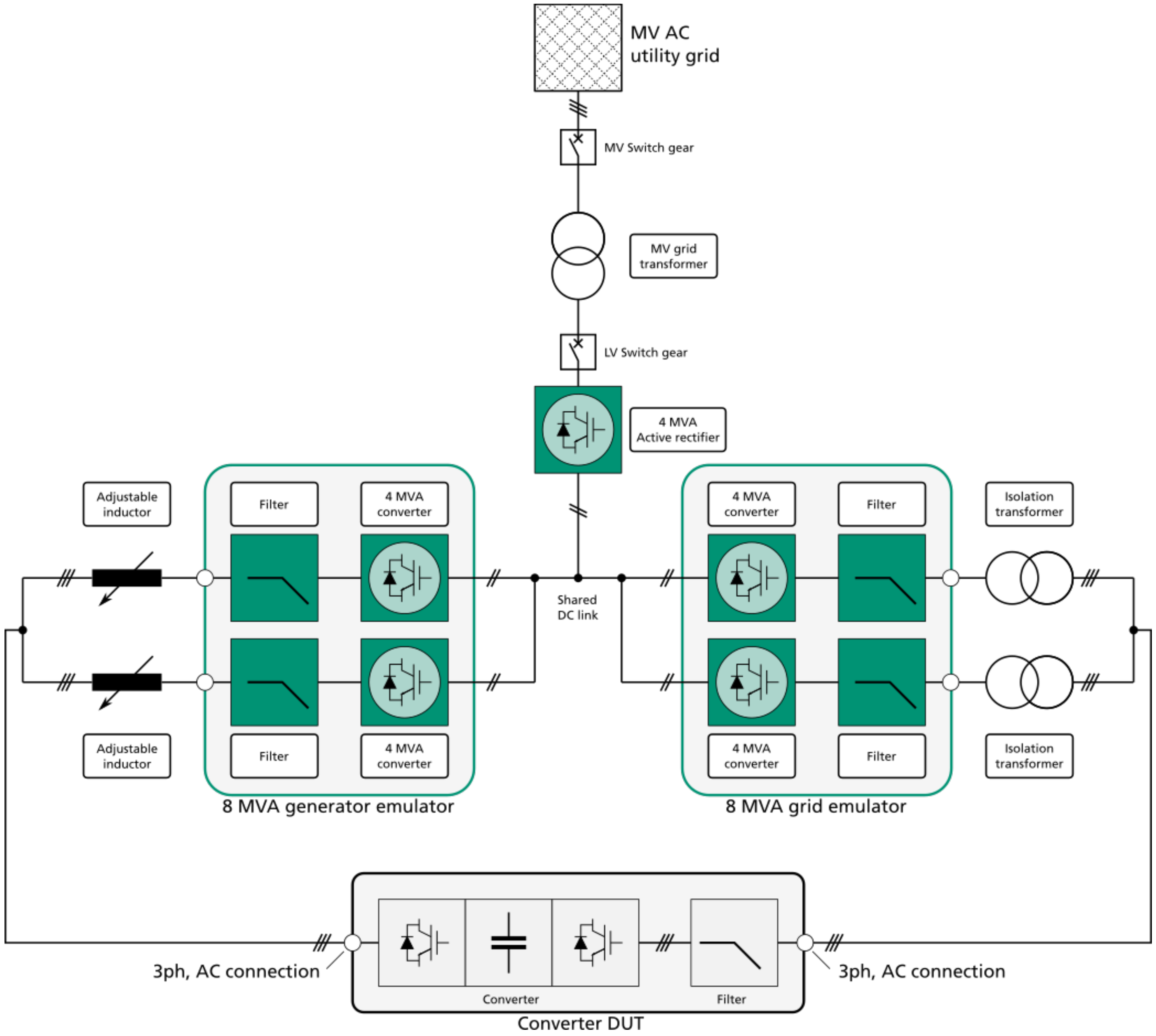
PQ4Wind - Test bench

Single-line

- Three functional units
  - 1x Grid-facing active rectifier
  - 2x Generator emulator
  - 2x Grid emulator
  - Modules build on 8 parallel 3-level inverter
- Shared DC link
- Circular current flow suppressed by isolation transformer on grid emulator
- Suppression of uncontrolled currents by adjustable inductances 1-15 uH
- Optimized cable routing to reduce parasitic effects



Source: IWES

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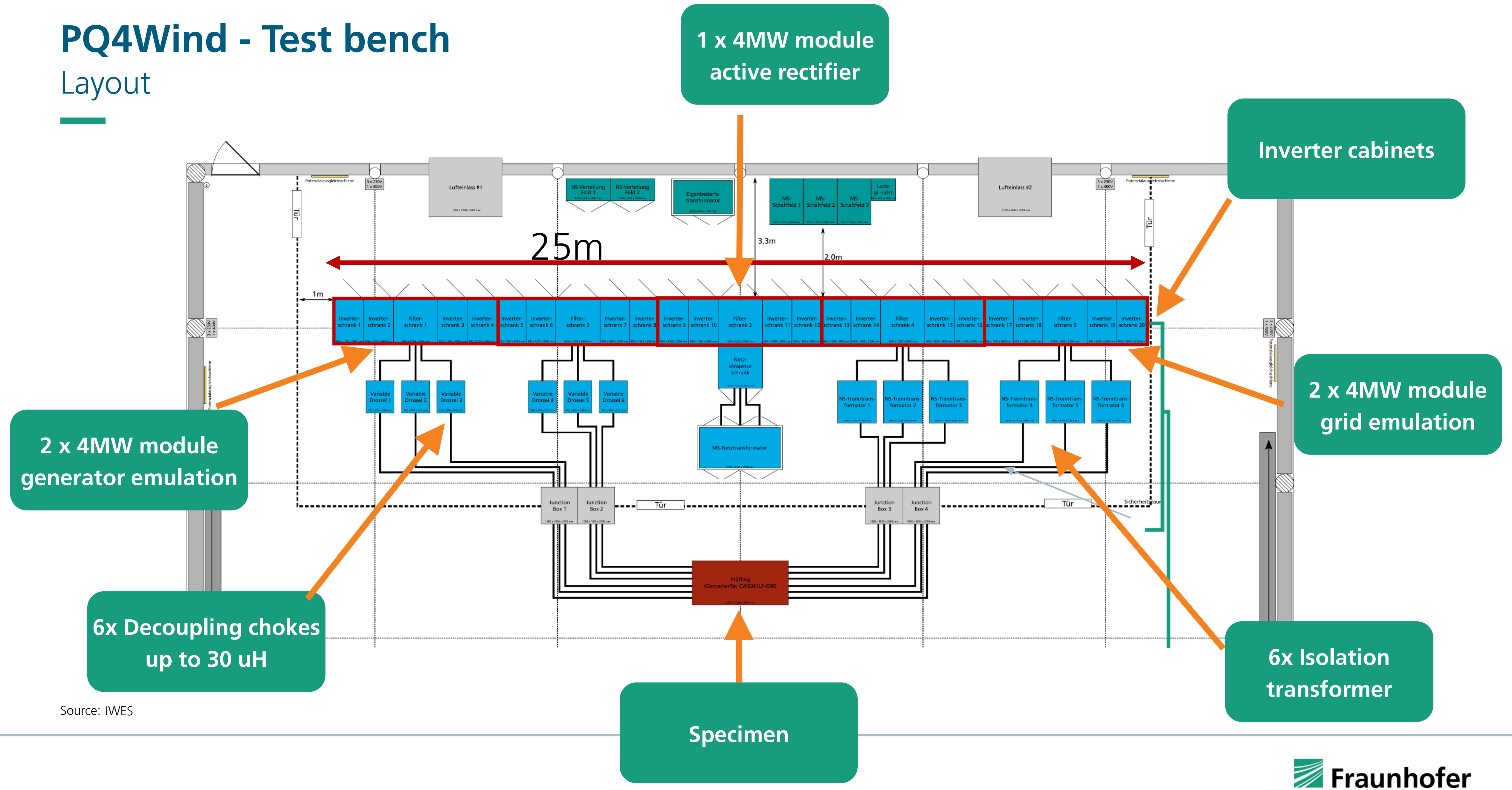
PQ4Wind - Test bench

Layout



Source: IWES

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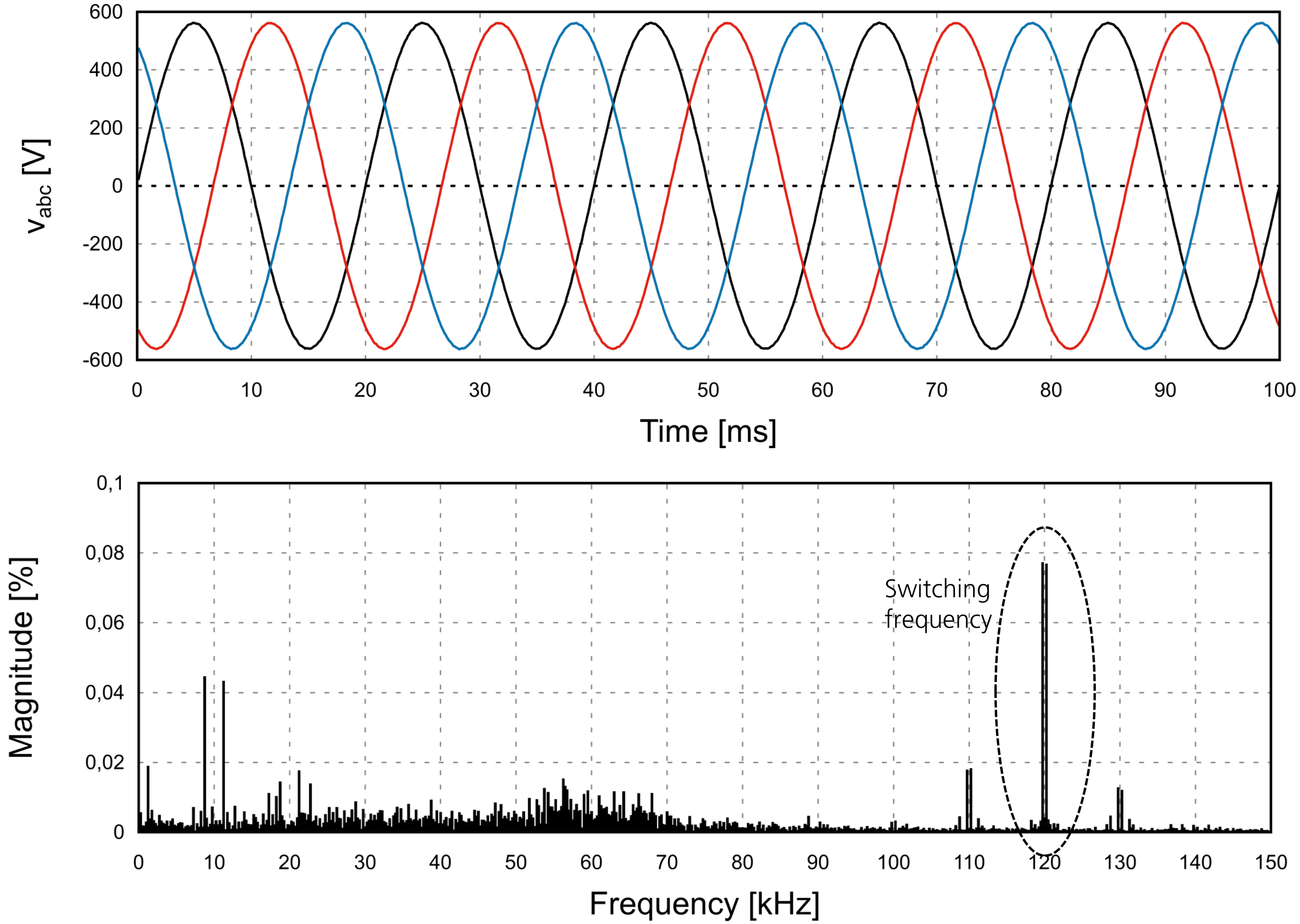
PQ4Wind: Grid emulator

Ideal grid

- Very low harmonic distortion
- Fundamental: 50 Hz, 690 V_{RMS}
- Individual harmonics < 0.1%
- Full load THD < 0.25 %



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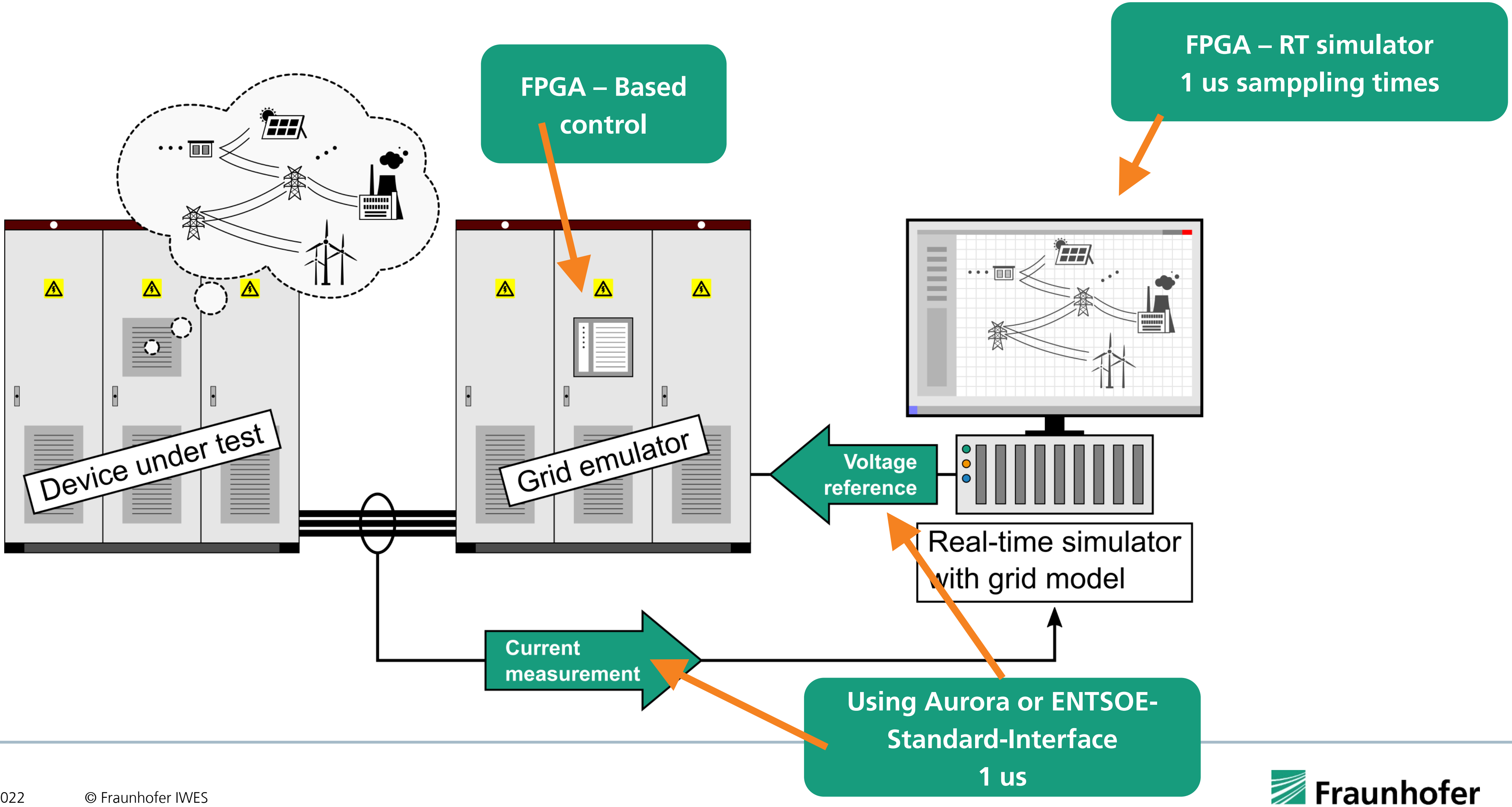
PQ4Wind - Power Hardware-in-the-Loop (PHIL) principle

Minimizing delay times



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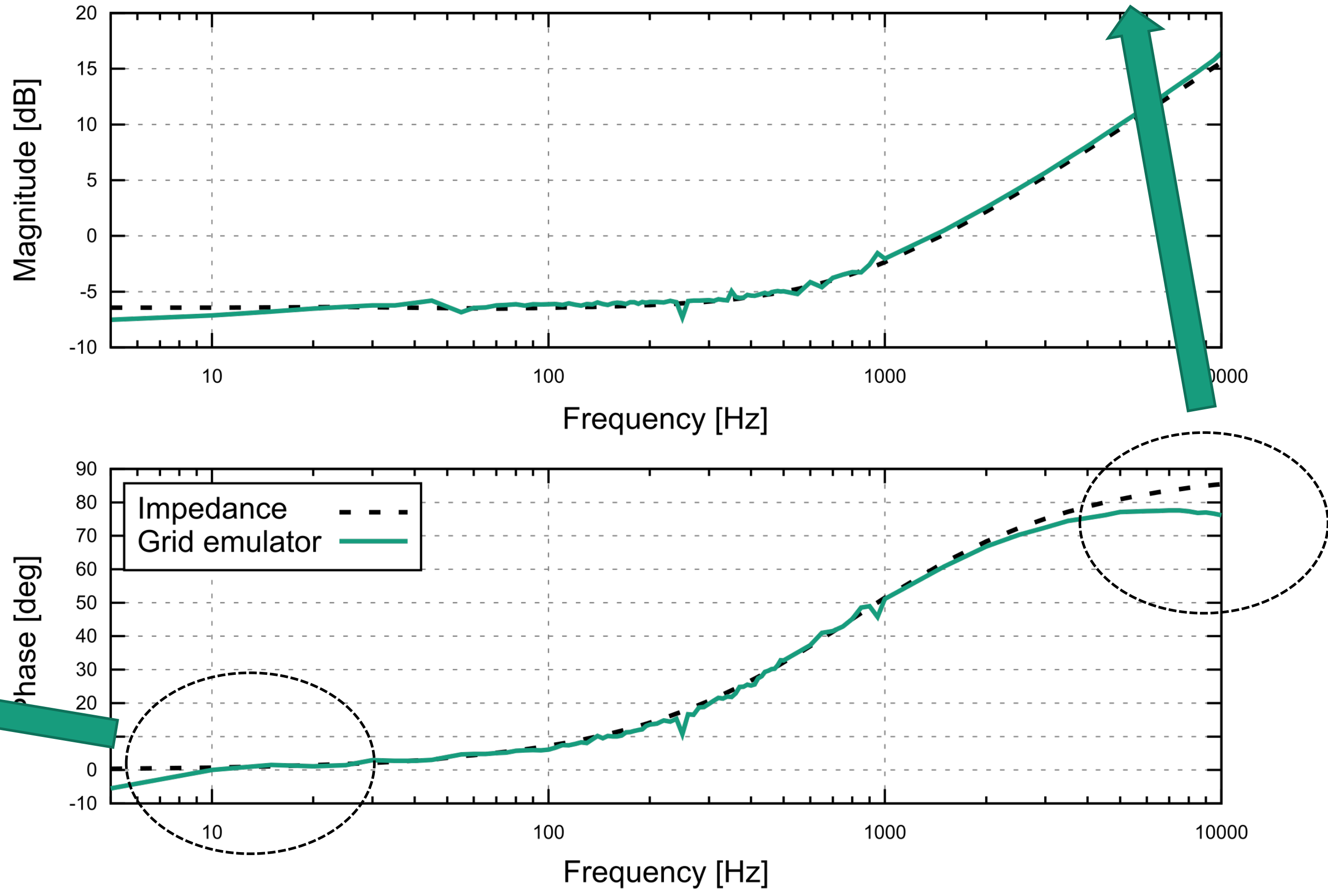
PQ4Wind - Grid emulator design and control evaluation

Scenario 2 – Simple grid impedance

Current transducer with cut off frequency of approx. 100 kHz

- Ohmic-inductive impedance (pos. seq.):
  $R_{emulated}$ = 500 mΩ
  $L_{emulated}$ = 100 µH
- At lower frequencies:
  Voltage amplitudes very small, isolation transformer
- At frequencies > 2 kHz: Increasing phase shift

At least 24-Bit resolution for measurements and processing is required



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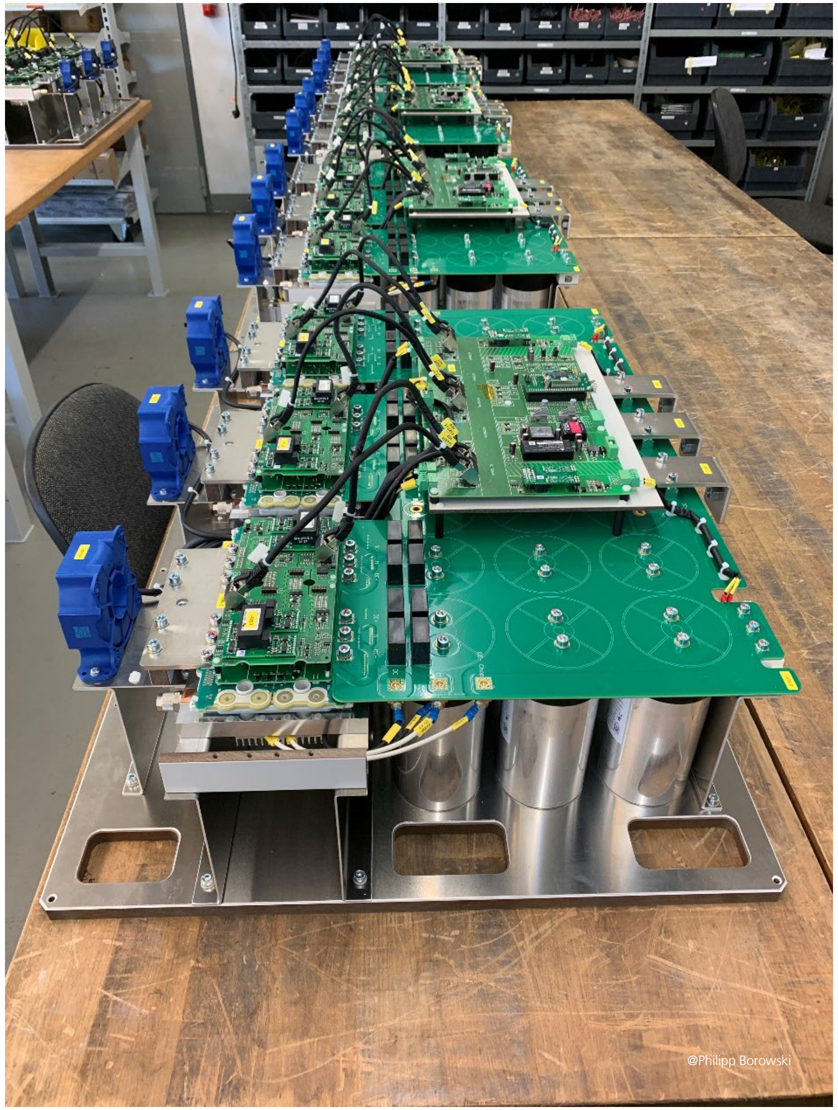
PQ4Wind – Test bench

Actual status

Commissioning
Q1 2023



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PQ4Wind – Summary

- Interaction studies providing value by validated Models
- Component certification will be key enabler
- PQ4Wind Inverter and component test rig with outstanding dynamic performance
- Starting discussion about objective model validation requirements

Thanks a lot for your attention!

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