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Insight into PQ4Wind Project

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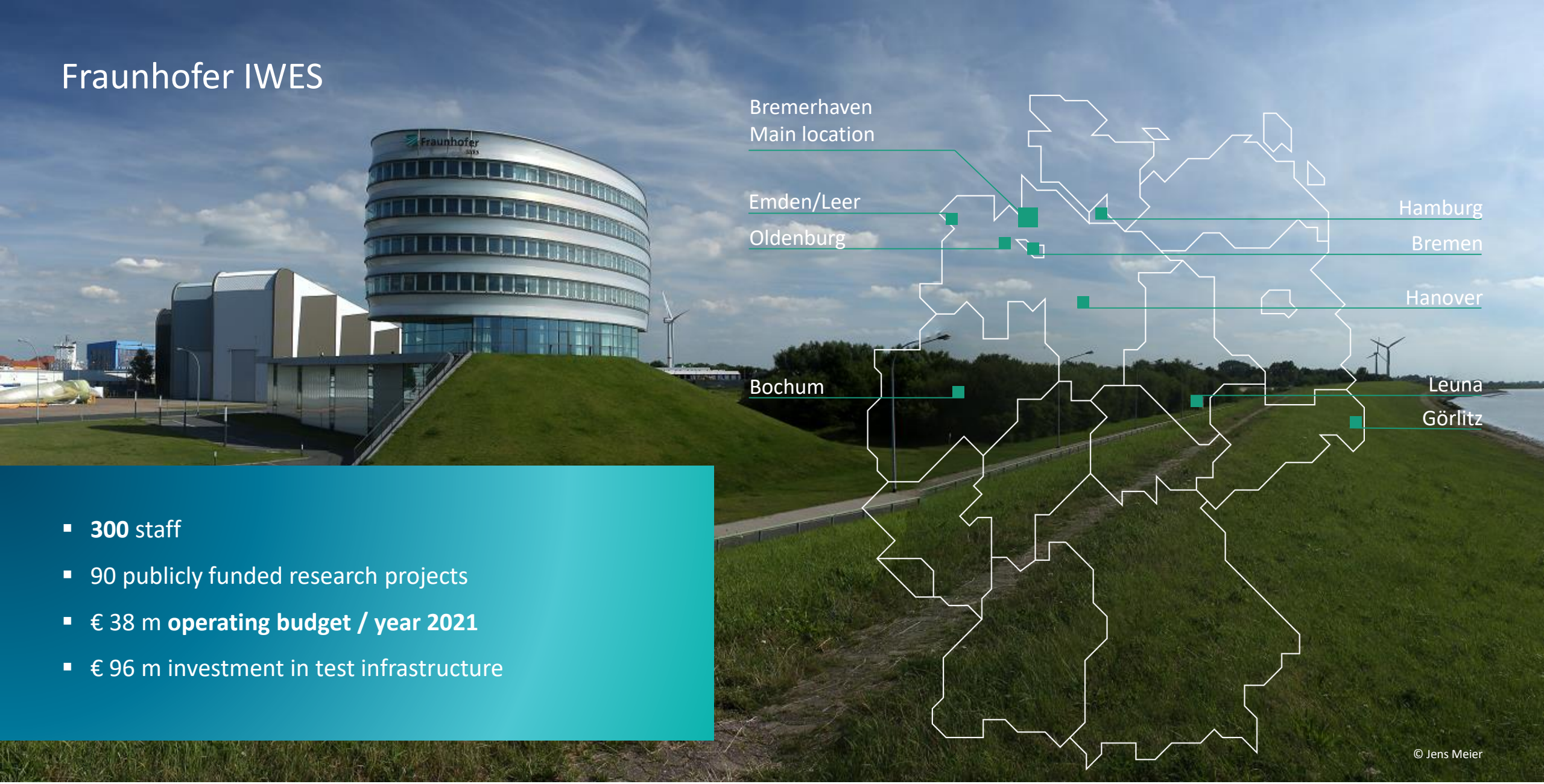
Fraunhofer IWES



- **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

Assessment of Soil Conditions Bremen

2009

70 m Rotor Blade Hall

1st Lidar Measuring Buoy Bremerhaven

2011 – 2012 – 2013

90 m Rotor Blade Hall Bremerhaven

Engineering Building

Test Center Support Structures Hanover

2014

DyNaLab Bremerhaven

2015

Application Center for Field Measurements Bremerhaven

BladeMaker Bremerhaven

2016

Research Wind Turbine Bremerhaven

2017

Large Bearing Test Bench Hamburg

2019

Application Center for Integration of Local Energy Systems Hamburg

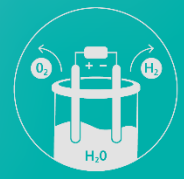
Hydrogen Lab Leuna

2021

Hydrogen Lab Bremerhaven

2022

Hydrogen Lab Görlitz



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Research and service spectrum of IWES

Test infrastructure

Digitalization

Offshore

Hydrogen

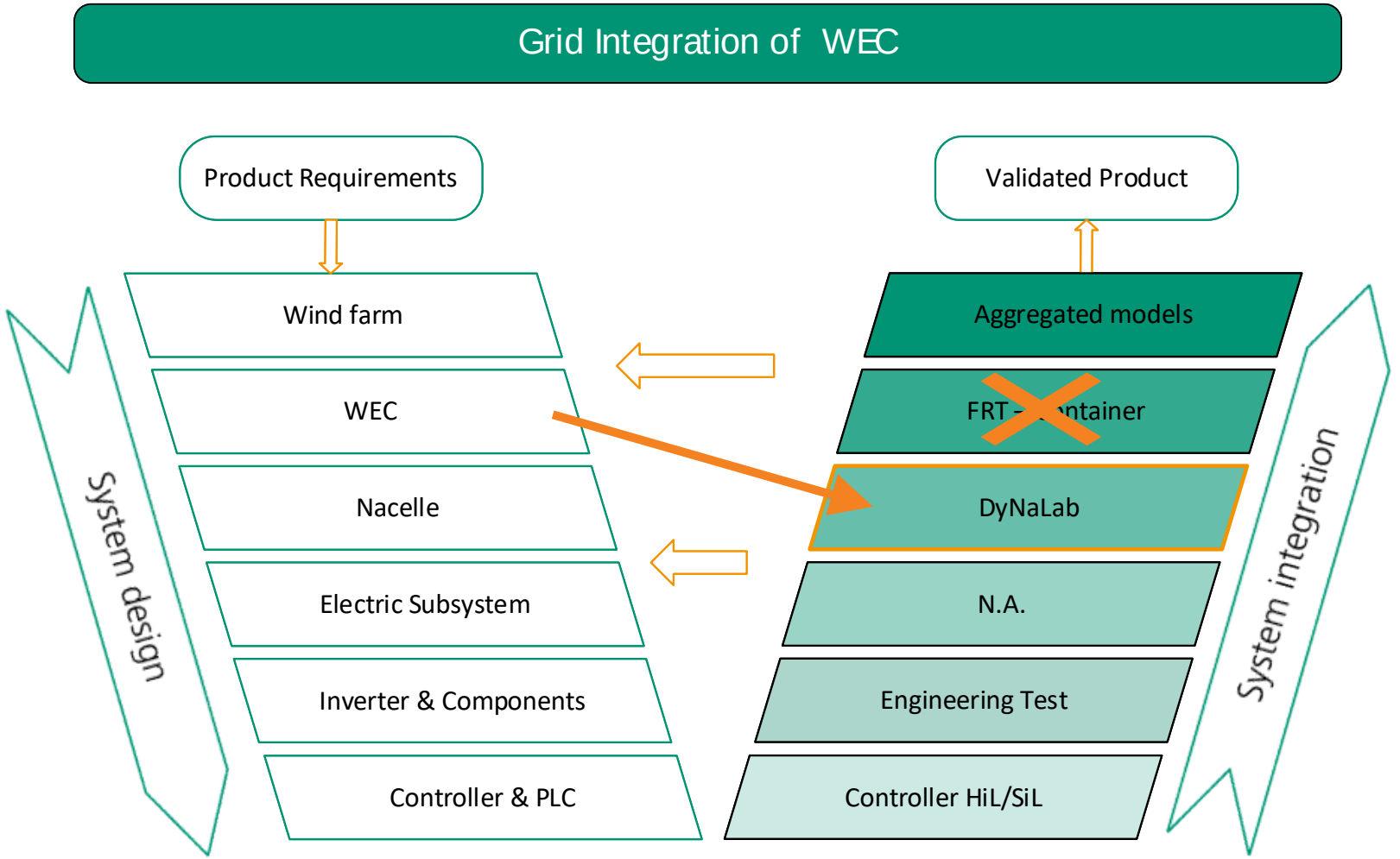
Nacelle testing

Grid integration testing of wind turbines on test benches

Fraunhofer IWES

Motivation grid integration testing of wind turbines on test benches

Agenda 2012



- Substitute field testing
- Performing all tests according to IEC 61400-21-1 or TR3 on test benches
- Reduce time to marked
- Saving cost
- FRT tests cause the biggest problems in the field

- **Implement what is technically feasible**

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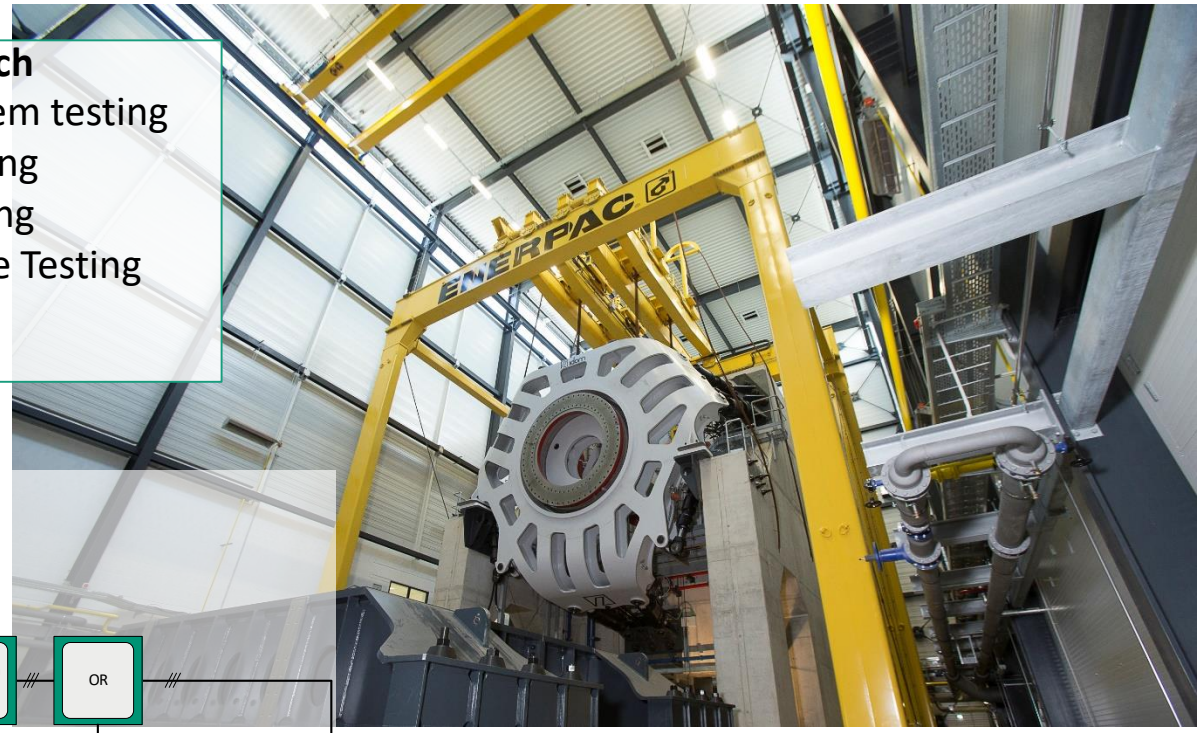
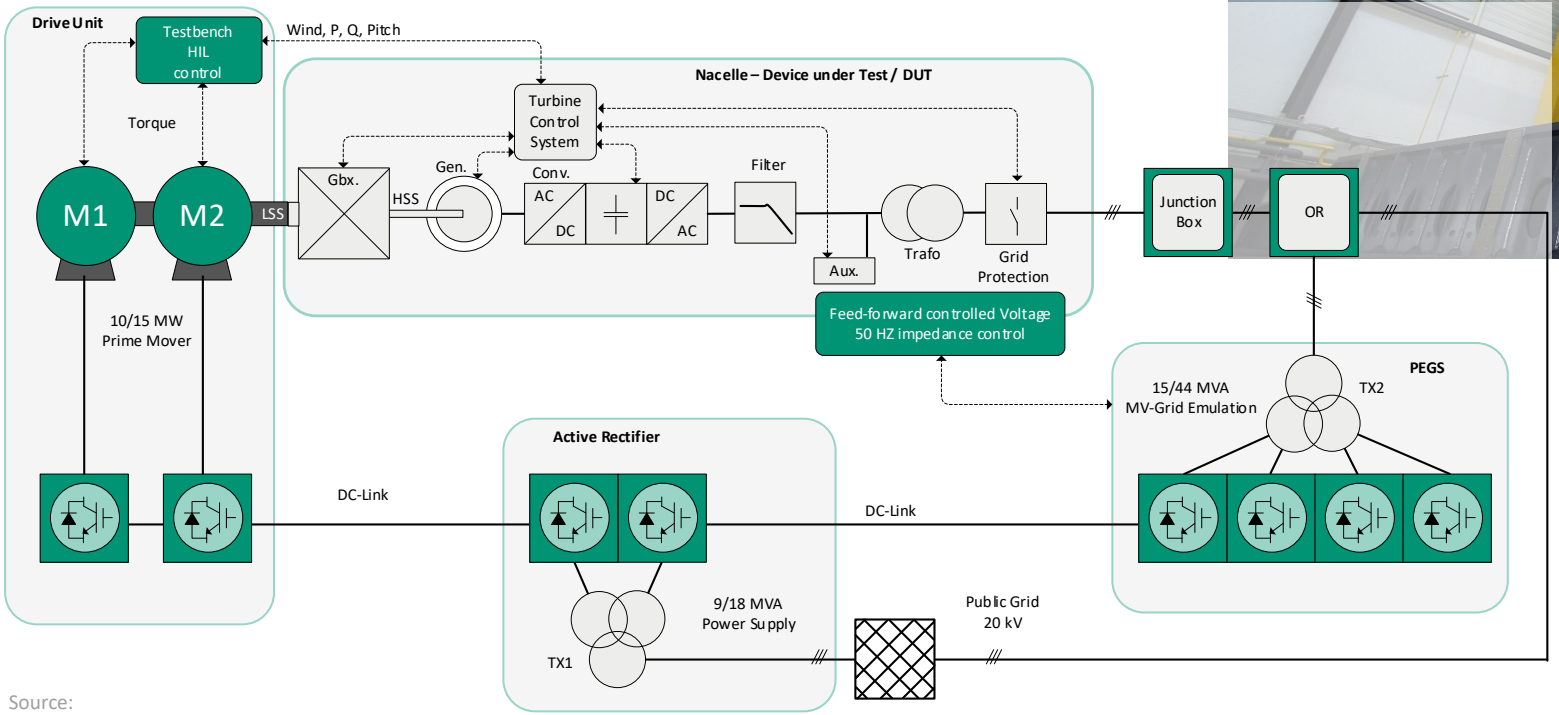
DyNaLab
Keypoints

Nacelle test bench
- Functional system testing
- Drive train testing
- Generator testing
- Grid compliance Testing





Key points
- 10 MW motor @11 rpm
- 8600 MNm torque
- 150% overload capacity
- Highest control performance
- DUT attachment system in 5 DOF
- 44 MVA medium voltage grid emulator

Source:

Fraunhofer IWES

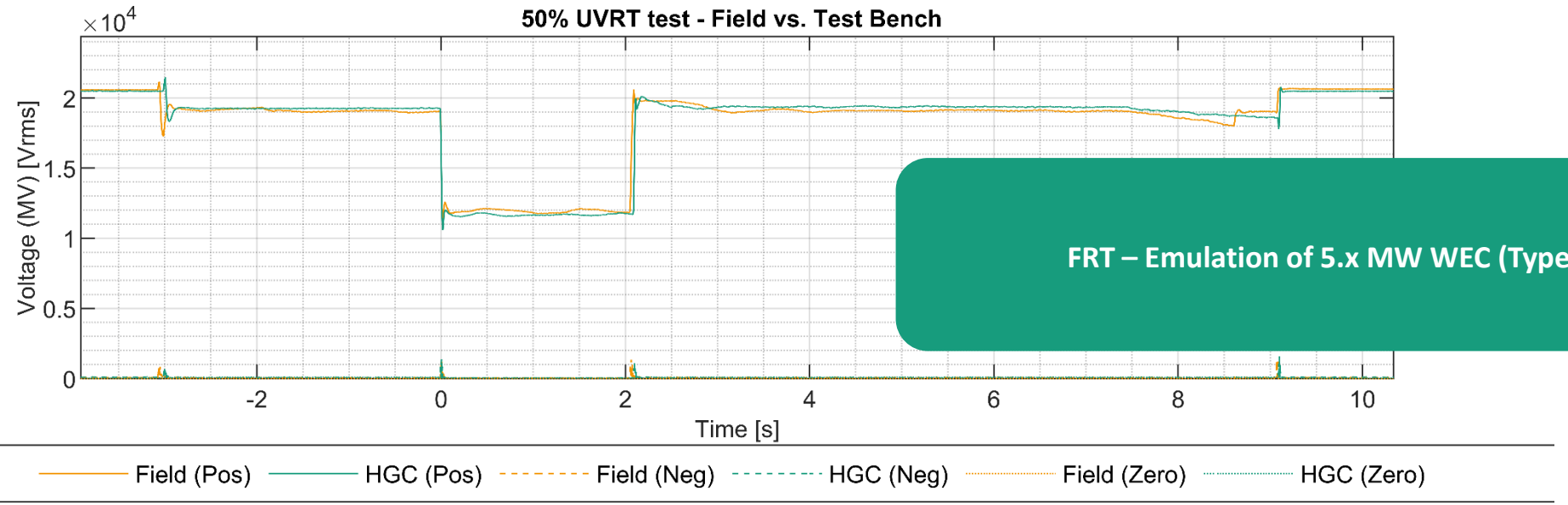
Grid Emulator

Keypoints

- Continuous power 15.3 MVA
  - 4 x 11 = 44 MVA installed inverter power for transient events
- 10/20/33 kV nominal Voltage
  - Dynamic voltages for UVRT and HVRT events
  - Voltage 0% till 140%
- Frequency 50/60 Hz +- 5 Hz
  - RoCoF 19,6 Hz/s
- Low THD_{50} below 3 %
  - Various HF-Filter settings possible, changing switching frequencies
- Grid characteristic changeable by emulation
  - Weak till strong grid conditions
  - Dynamic changes of grid impedance
- Semi automatic testing operation

Source:

FRT Emulation with 44 MVA grid emulator



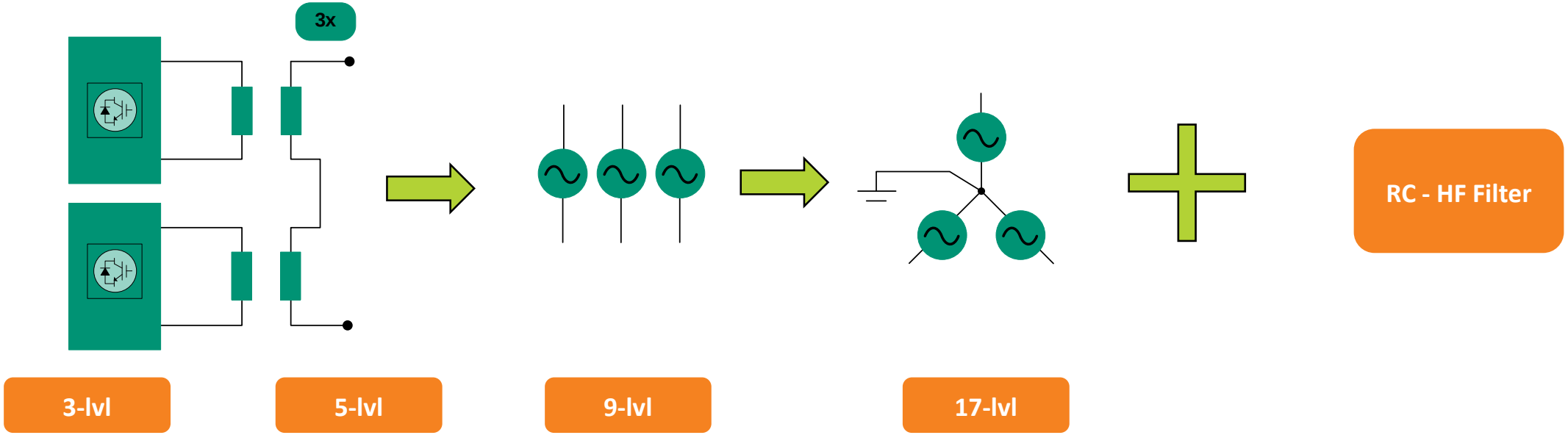
FRT – Emulation of 5.x MW WEC (Type3)

Hamonic measurements

Source:

Grid Emulator

Build on industrial proven MV IGCT technology



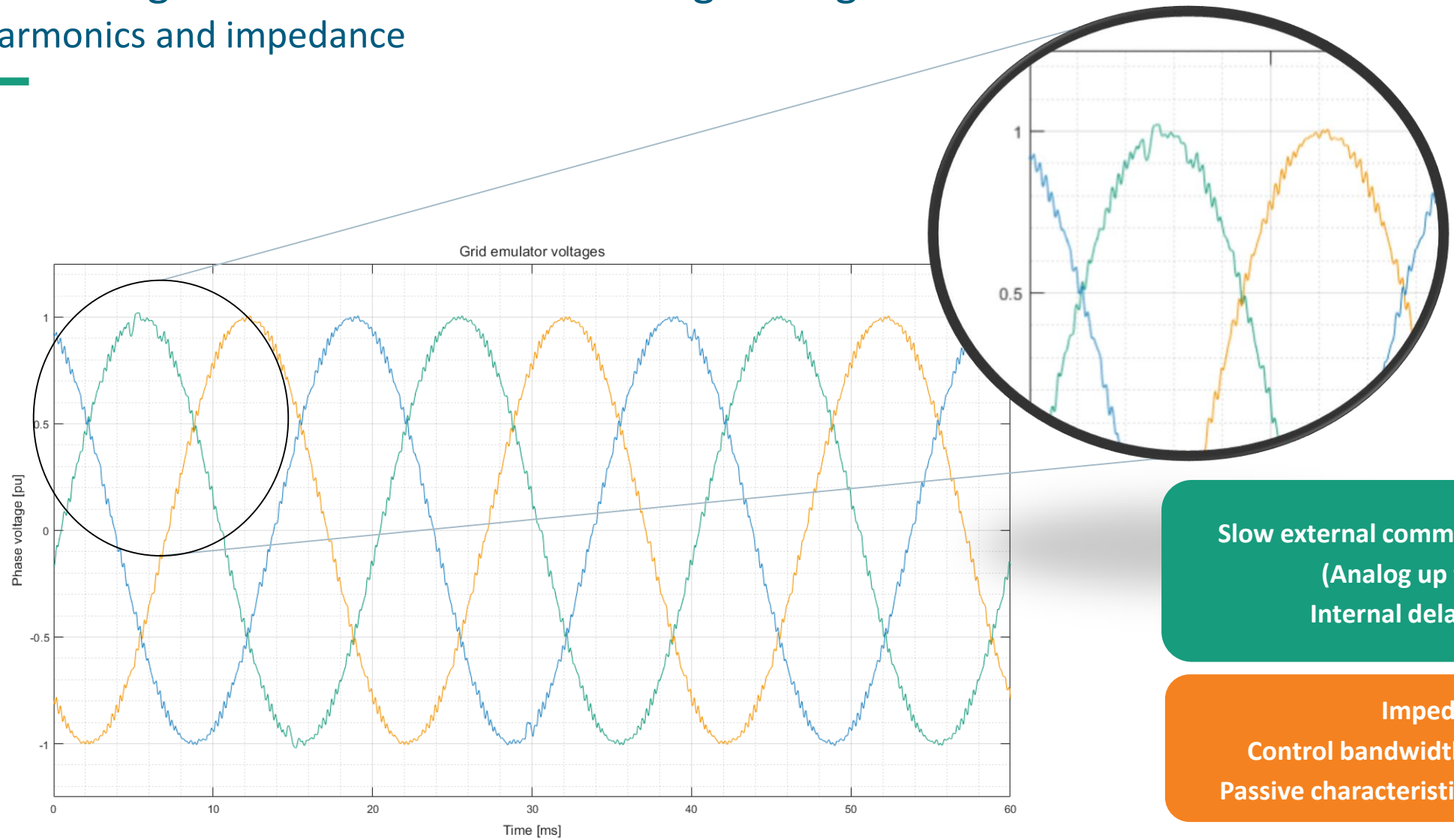
- Low switching frequency
- Lower harmonics cancellation due to transformer configuration

- Highest controllability due to single transformer topology
- High cut-off frequency of filter to allow dynamic operation

Source:

Technological drawbacks of multi-megawatt grid emulators

Harmonics and impedance



$THD_{U\_50} < 2\%$
$THD_{U\_200} < 5\%$
Artefacts in voltages

Slow external communication Interface
(Analog up to 40 kHz)
Internal delay of 255 us

Impedance
Control bandwidth approx. 100 Hz
Passive characteristic load dependency

So

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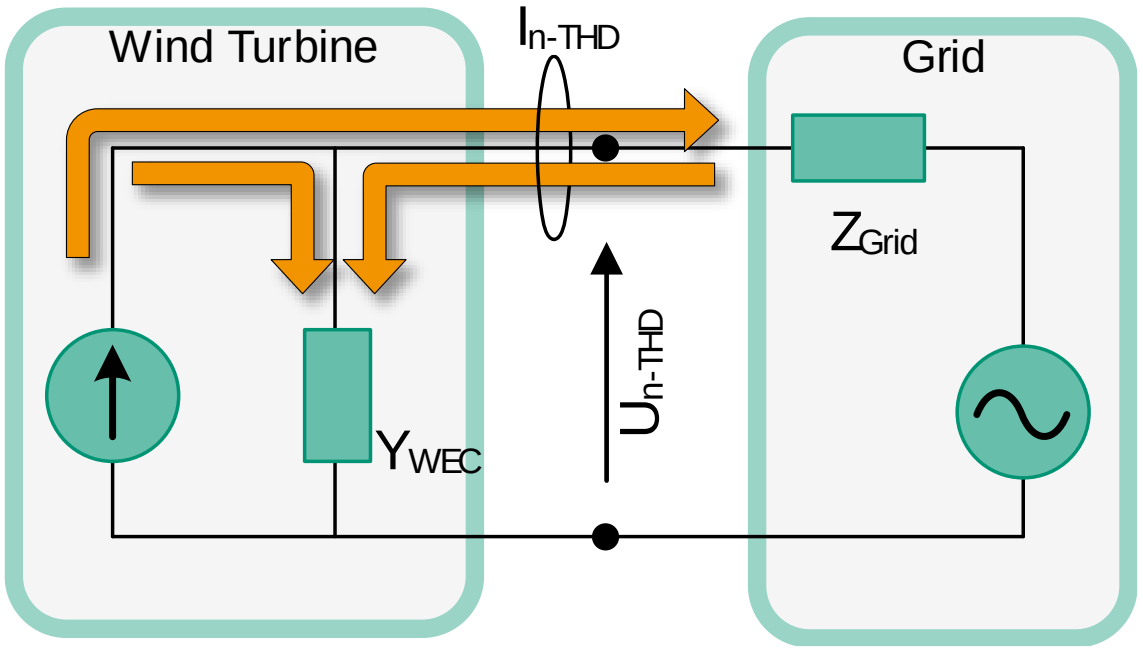
Motivation of PQ4Wind

Generalized harmonic measurement and impedance characterization

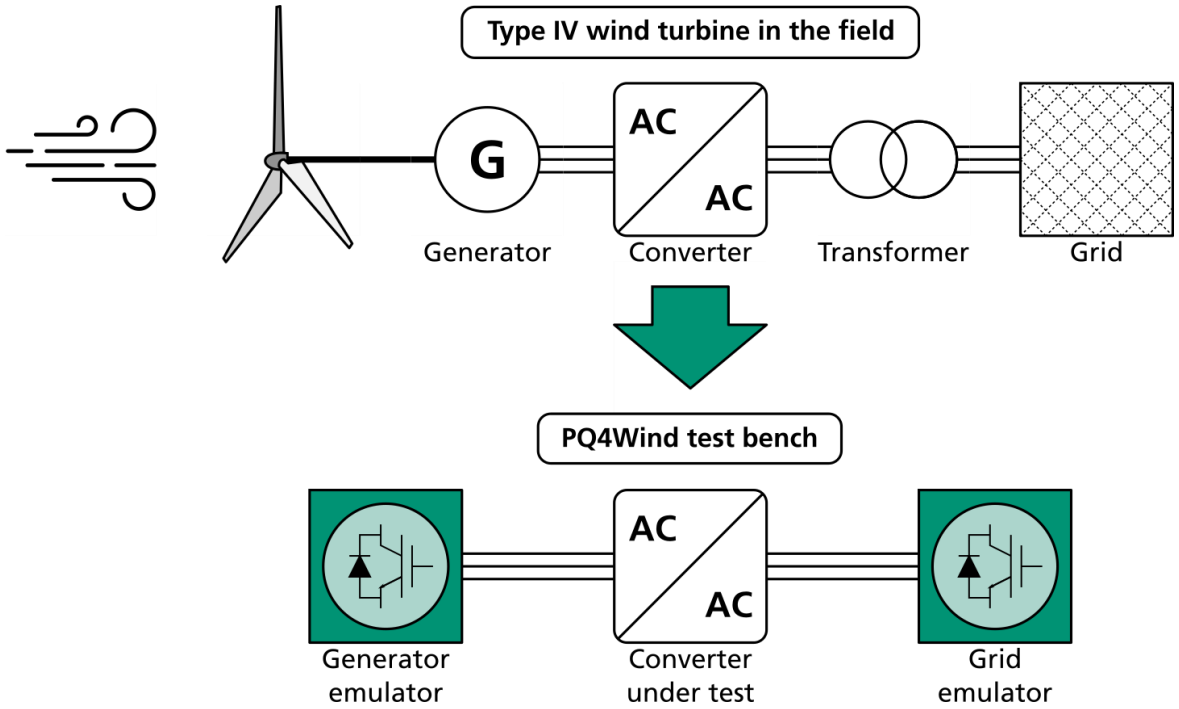
- Harmonic measurement method in IEC is only valid for single measurement location
  - Unknow background noise
  - Unknow grid impedance
  - Unknow wind turbine
  - Single point measurement

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



Source:

PQ4Wind - Testing on component level



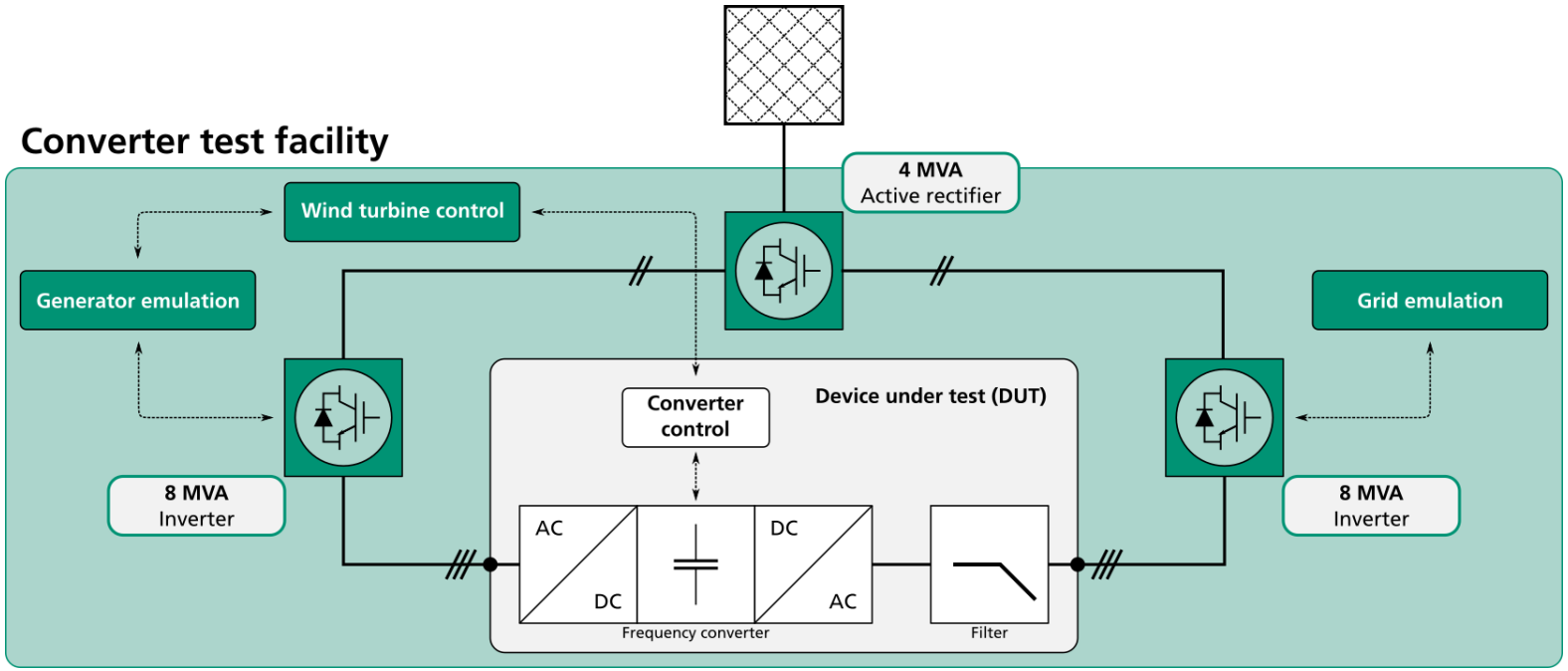
PQ4Wind test bench	
Apparent power	8 MVA
Phase-to-phase voltage	1050 V_{RMS}
Fundamental frequency	40-70 Hz
Total harmonic distortion	<< 1 % at 50 Hz
Effective switching frequency	> 100 kHz
Harmonic injection	Up to 10 kHz
Impedance emulation	Up to 10 kHz
Fault ride through capability	150 % HVRT at 690 V_{RMS} 0 % LVRT (ZVRT for max. 2 s)
Commercial availability	2023

Source:

PQ4Wind

Single-line

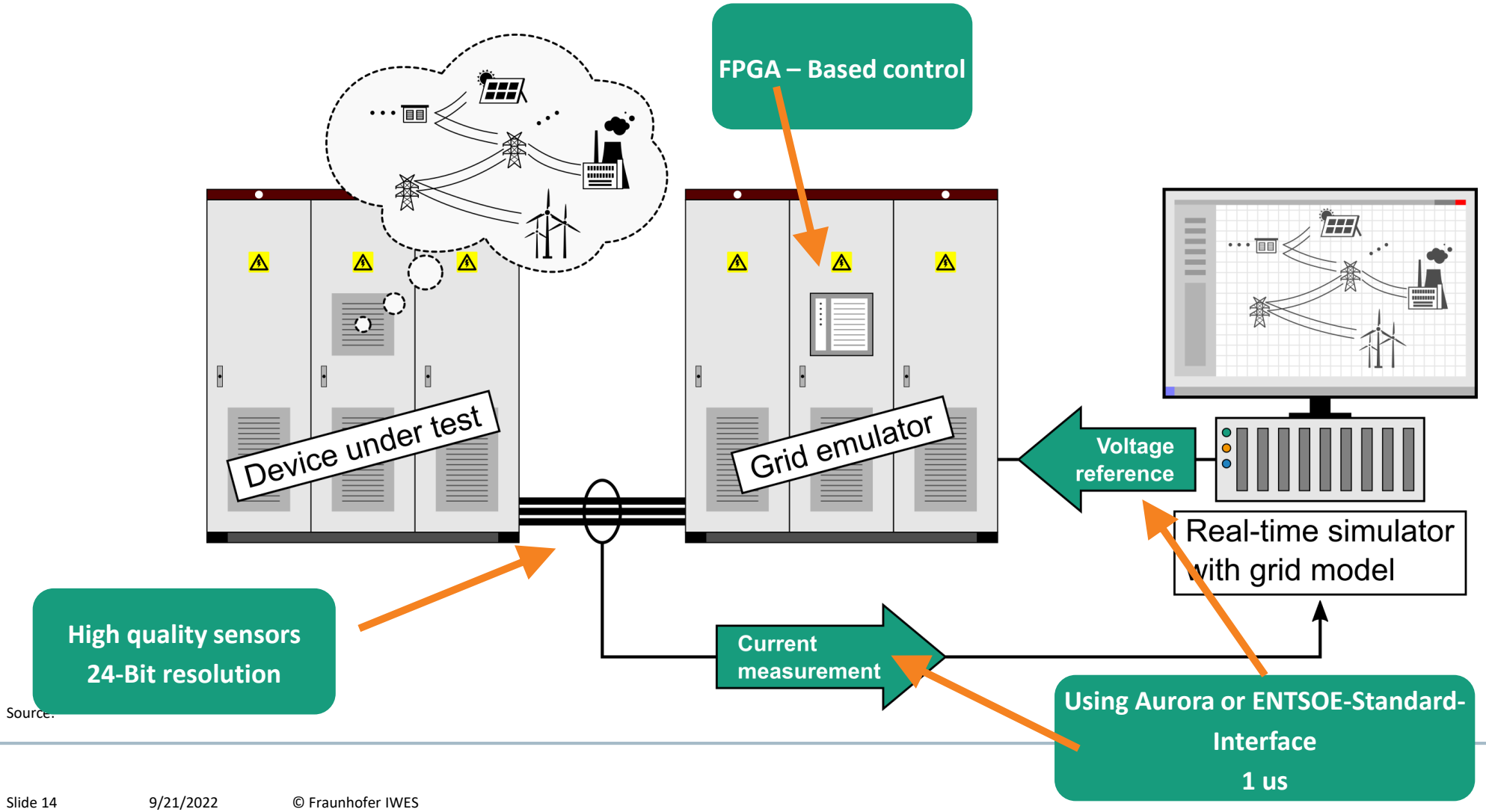
- Three functional units:
  - Grid-facing, active rectifier
  - Generator emulator
  - Grid emulator
- Shared DC link
- Circular power flow
- Fast switching converters (fsw,eff > 100 kHz)



Source: Test bench setup

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

Minimizing delay times



Source:

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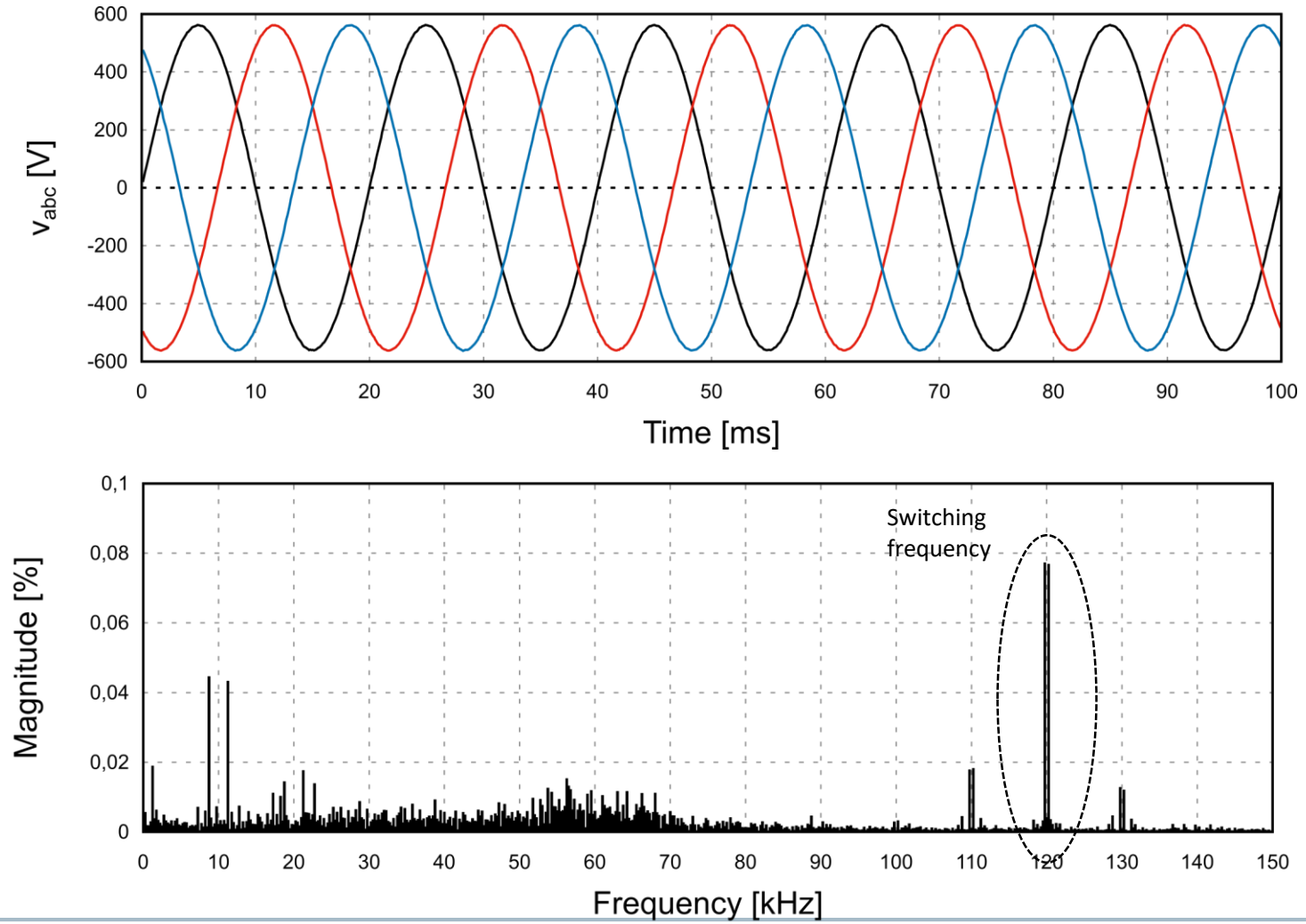
PQ4Wind: Grid emulator

Scenario 1 – Ideal grid

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



Source:

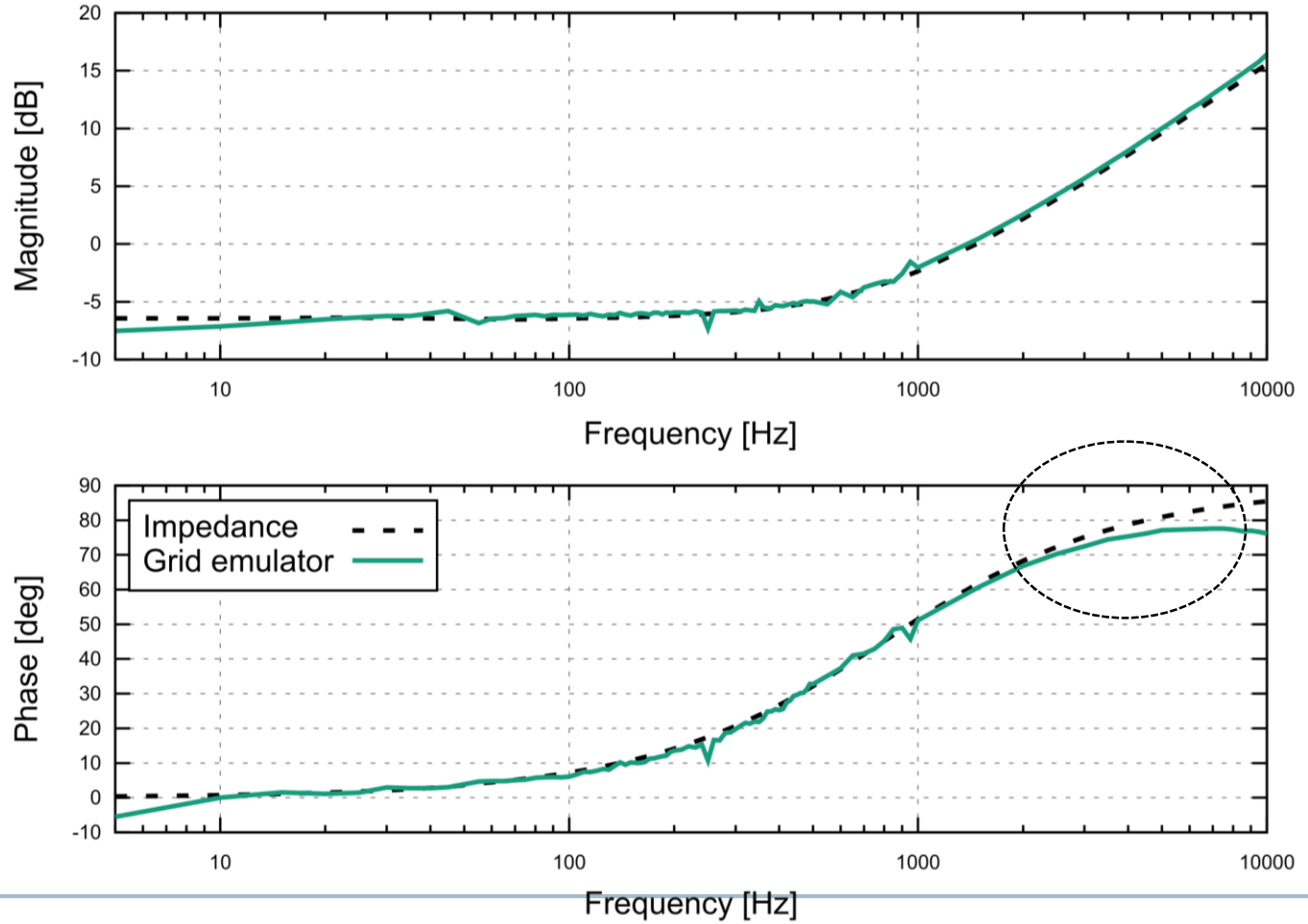
Fraunhofer IWES

PQ4Wind: Grid emulator

Scenario 2 – Simple grid impedance

- 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

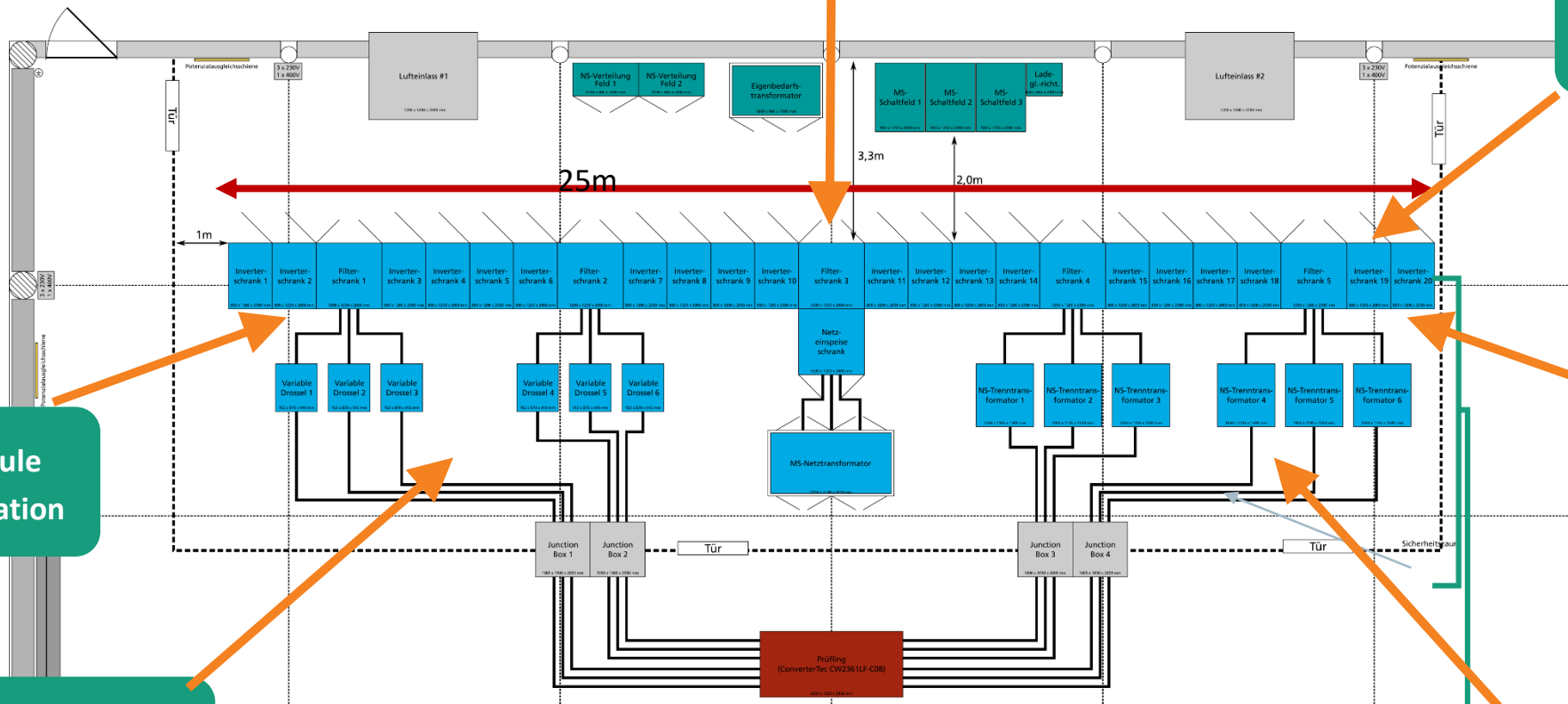


Source:

Fraunhofer IWES

PQ4Wind: Test bench

Layout



1 x 4MW module active rectifier

Inverter cabinets

2 x 4MW module grid emulation

2 x 4MW module generator emulation

6x Decoupling chokes up to 30 uH

6x Isolation transformer

Specimen

Source:

Fraunhofer IWES

PQ4Wind: Test bench

First cabinets

Commissioning
Q1 2023

Source:

Thanks a lot for your attention!

Fraunhofer IWES

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