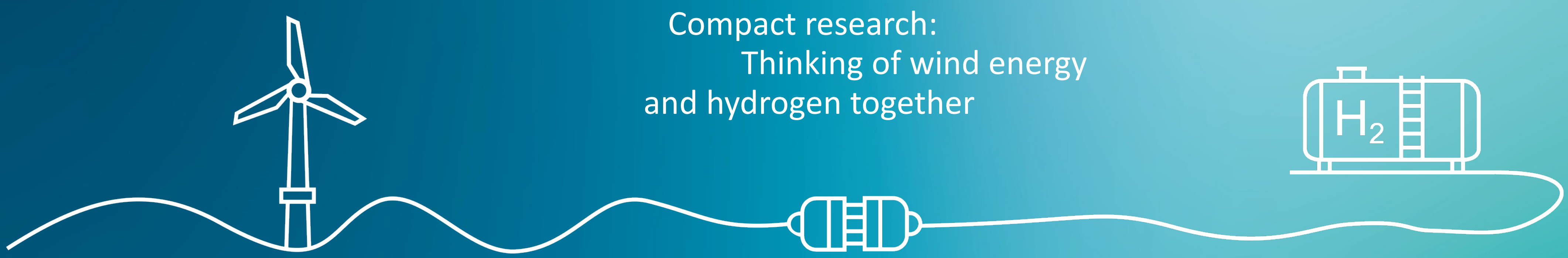


8th International Workshop on Grid Simulator Testing of Energy Systems and Wind Turbine Drivetrains

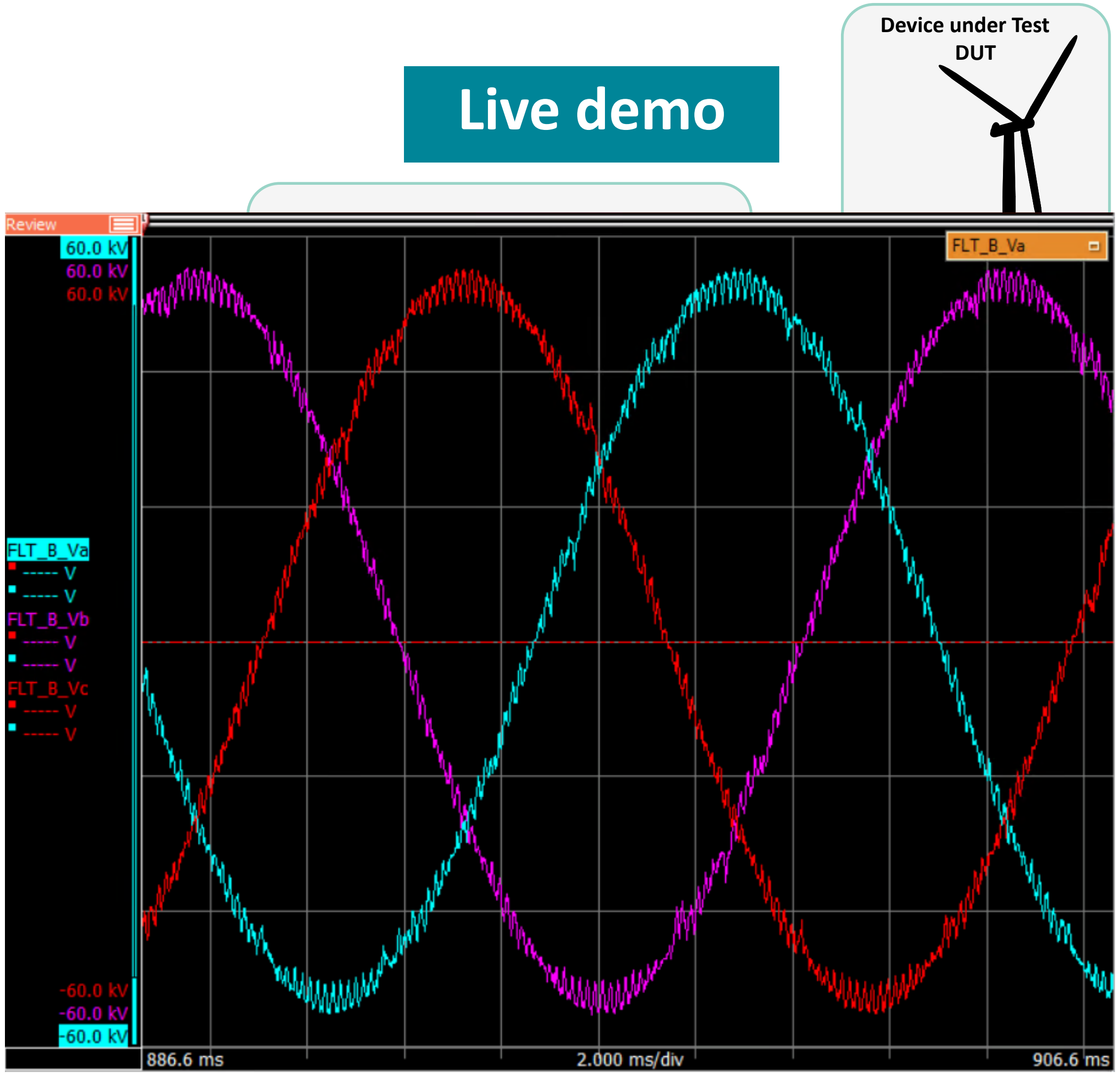
From Requirements to Reality: Early Insights into Islanding Testing at Fraunhofer IWES

Florian Hans

Recap of the workshop in Bremerhaven in 2024

Mobile Grid

A new generation of grid simulators



Improvement over other testing solutions

- New real-time concept using
  - Fast measurement and communication chain
  - Fast referencing channel with instantaneous values
  - Models on Typhoon HIL606 with sampling time of 25µs
  - Possibility to connect other real-time simulators

Objectives beyond conventional testing

- More realistic PHIL simulations
- Enabling field tests for novel ancillary services, e.g.,
  - Black start
  - Grid forming / islanding testing

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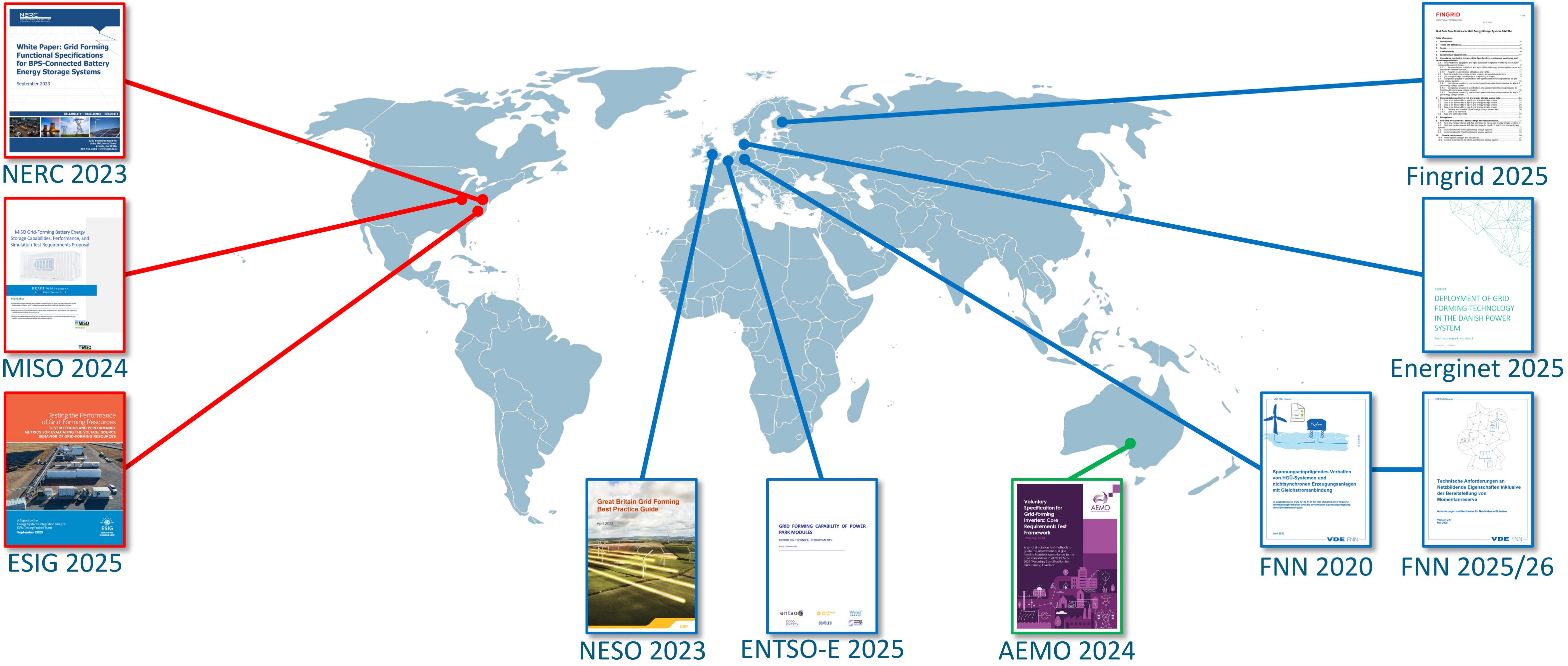
Landscape of requirements for grid-forming properties

Geographical distribution and origins



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Requirements for grid-forming units

Overview

Year	Synchr. operation	Frequency control	Voltage control	Damping	FRT behavior	Power quality	Black start	Island operation
VDE FNN 2020		✓		✓	✓			✓
NESO 2023	✓	✓	✓	✓	✓			
NERC 2023	✓	✓	✓	✓	✓	✓	✓	✓
AEMO 2024	✓	✓	✓	✓	✓	✓	✓	✓
MISO 2024		✓	✓	✓			✓	✓
Energinet 2025		✓	✓	✓	✓			✓
Fingrid 2025		✓	✓	✓	✓	✓		✓
ESIG 2025			✓	✓				
ENTSO-E 2025		✓	✓					✓
VDE FNN 2026	✓	✓	✓	✓	✓			✓

Extension of *Summary of GFM capability & Performance Requirements Driven by System Needs* by Global Power System Transformation Consortium, May 2024

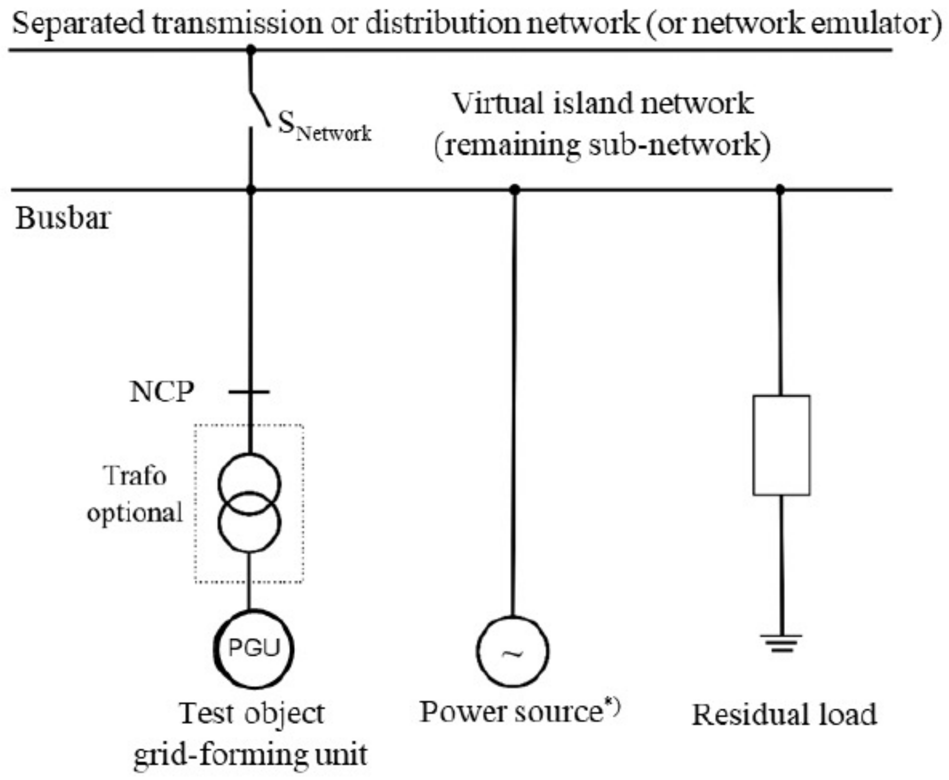
From requirements to testing
Verifications for virtual island network operation

Most important document in Germany

- **VDE FNN**: *Forum Network Technology* in the German Association for Electrical, Electronic & Information Technologies
- **Guidance (Hinweis) document:** *Technical requirements for grid-forming capabilities including provision of inertia - Requirements and verifications for grid-forming units*
- Not binding, but considered as *transitional document* until relevant VDE guidelines / European Network Codes are revised

Test environment

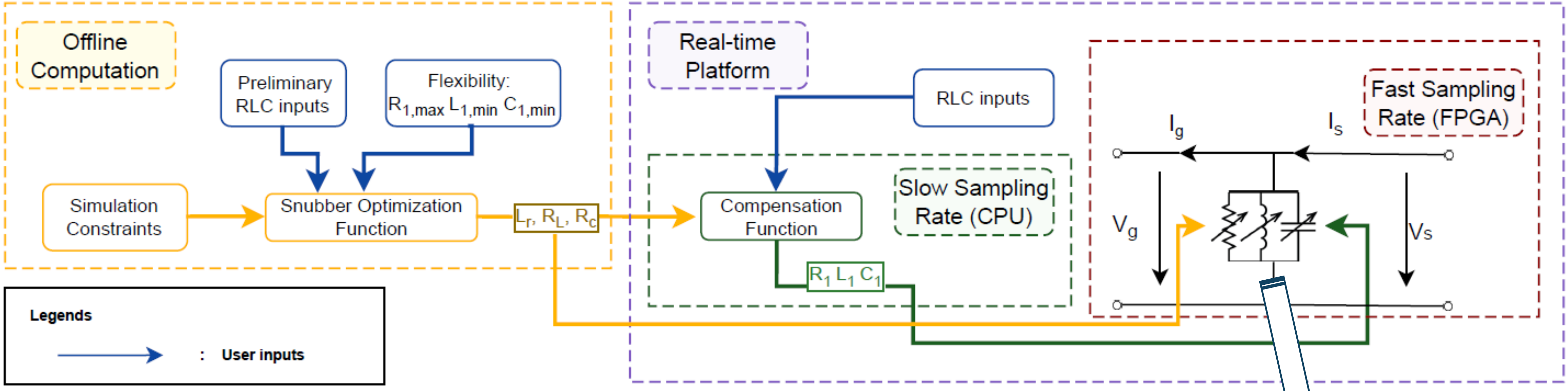
- Availability of adjustable load
  - switchable load banks
  - converter-based loads with adjustable *P*-range and constant power or resistance characteristics
- Loading condition from the technical minimum power PEmin,E to the maximum active power PEmax



Source: VDE FNN*: Technical requirements for grid-forming capabilities including provision of inertia - Requirements and verifications for grid-forming units*, Version 2.0, English version, October 2025

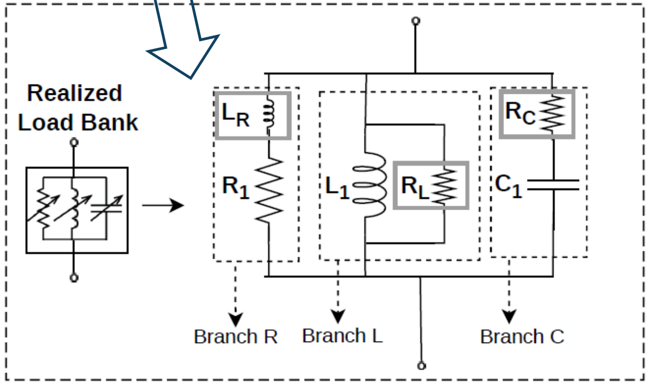
Flexible passive load bank simulation

Balancing act between flexibility, precision, and stability



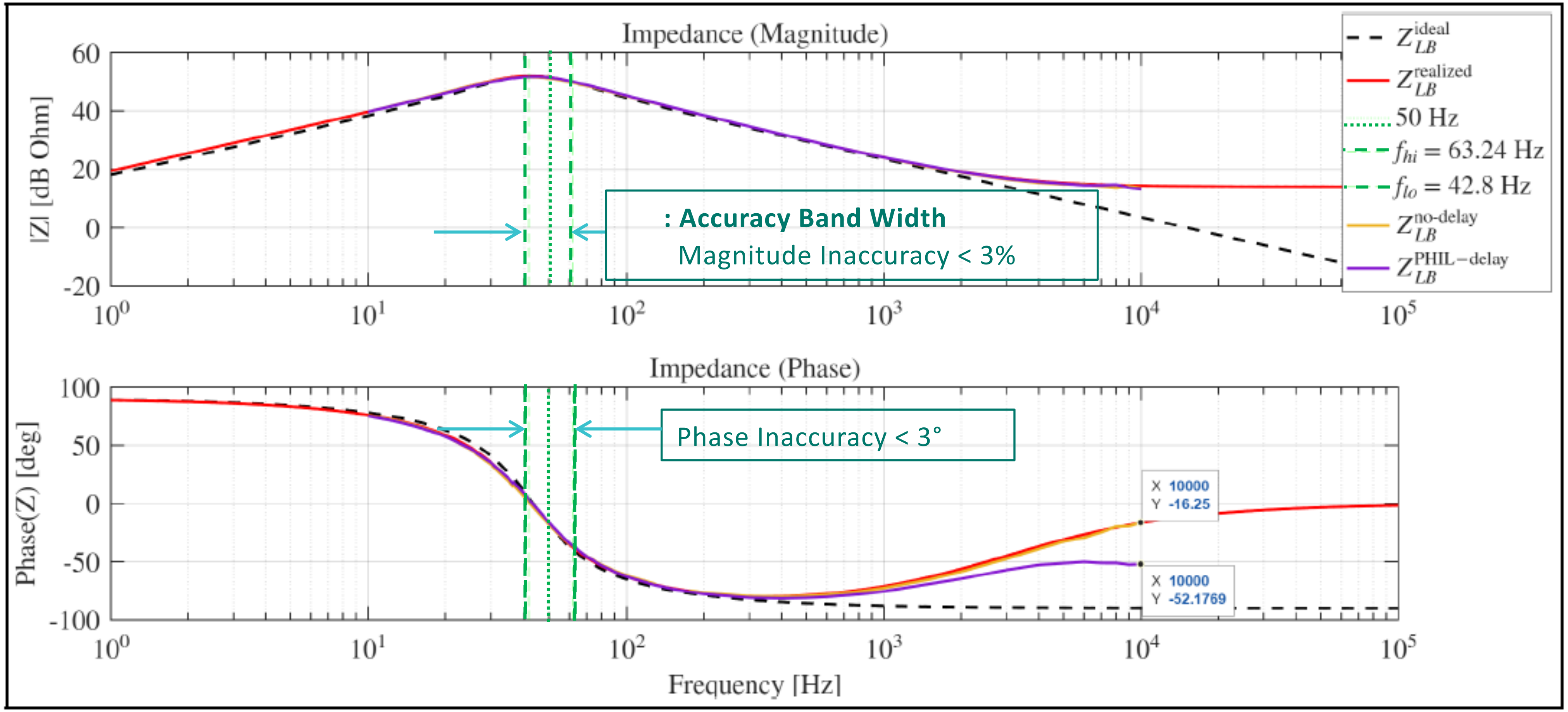
Framework

- **Main obstacle:** need of snubbers to avoid topological conflicts and numerical issues
- Two-step approach
  - Offline snubber optimization ensuring numerical stability under given constraints
  - Online compensation function ensuring accurate representation at and around fundamental frequency



Flexible passive load bank simulation

Balancing act between flexibility, precision, and stability - Accuracy assessment



From requirements to testing

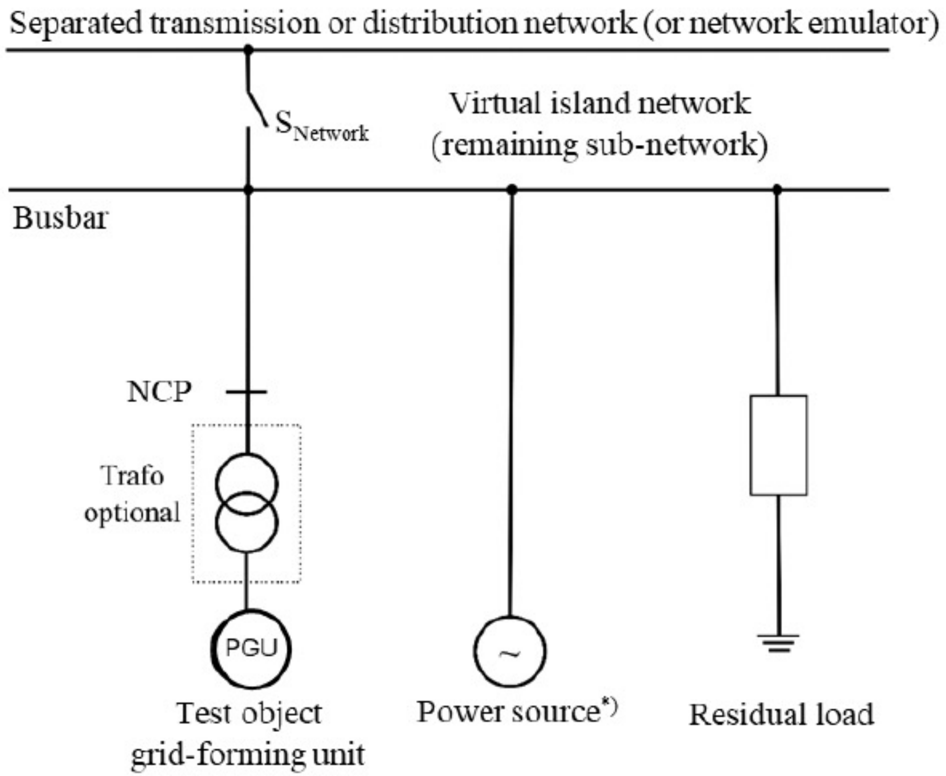
Verifications for virtual island network operation

Test environment

- Availability of adjustable load
  - switchable load banks
  - converter-based loads with adjustable *P*-range and constant power or resistance characteristics
- Loading condition from the technical minimum power PEmin,E to the maximum active power PEmax

Testing procedure

- Starting from steady-state network parallel operation
- Initial power of the grid-forming unit
  - Pmom > Presidual + 23% PEmax
  - Q/Pemax either 0, or max. ind, or max. cap.
- Open circuit breaker and switch to residual load with
  - 45% to 65% PEmax
  - -45% to -65% PEmax
- ➢ Ensure stable and well-damped operation, for at least 50 seconds



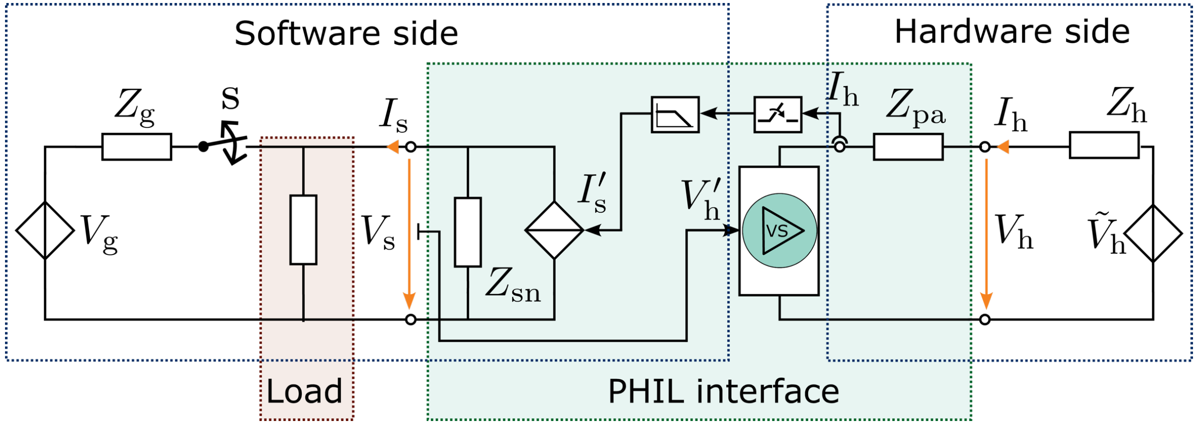
Source: VDE FNN*: Technical requirements for grid-forming capabilities including provision of inertia - Requirements and verifications for grid-forming units*, Version 2.0, English version, October 2025

PHIL control concepts

Voltage source vs. current source interface

Current focus of the first campaign at IWES

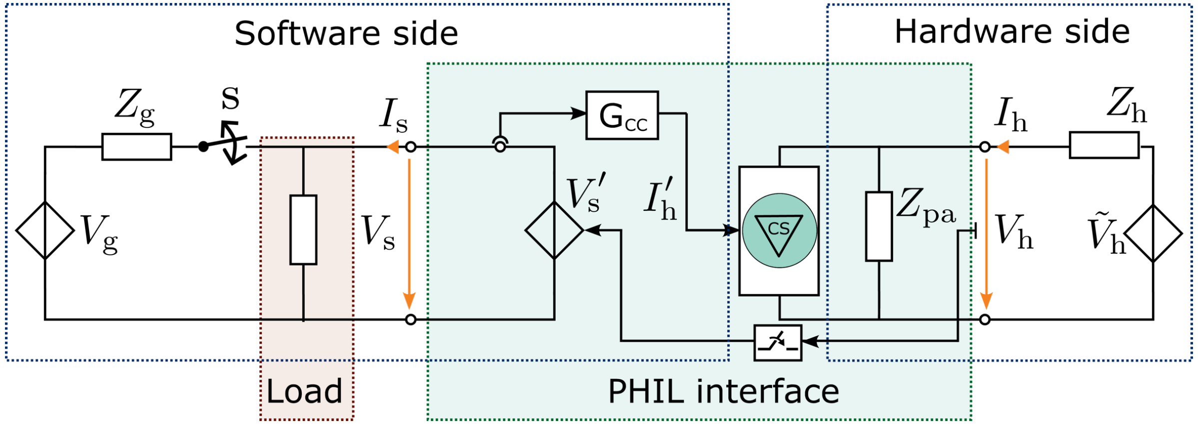
Voltage-type PHIL setup with feedback current filtering



- Requires implementation of
  - Software filter in feedback path for closed-loop stabilization
  - Snubber in parallel to virtual current source

➢ **Dynamic properties and impedance are defined by filters, snubbers, and the bandwidth of the grid emulator**

Current-type PHIL setup with current controlled emulator



- Requires implementation of
  - Synchronization unit (PLL) and current control of the grid emulator
  - Switching of the interface when falling into the island

➢ **Dynamic properties and impedance are defined by current control**

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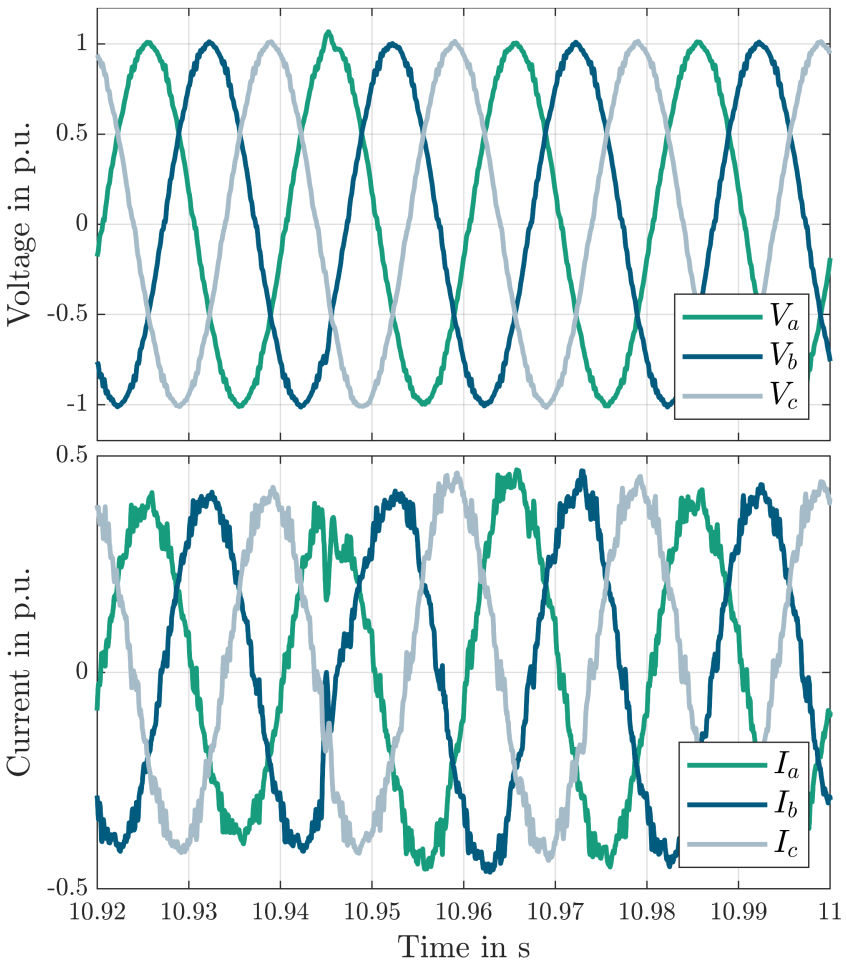
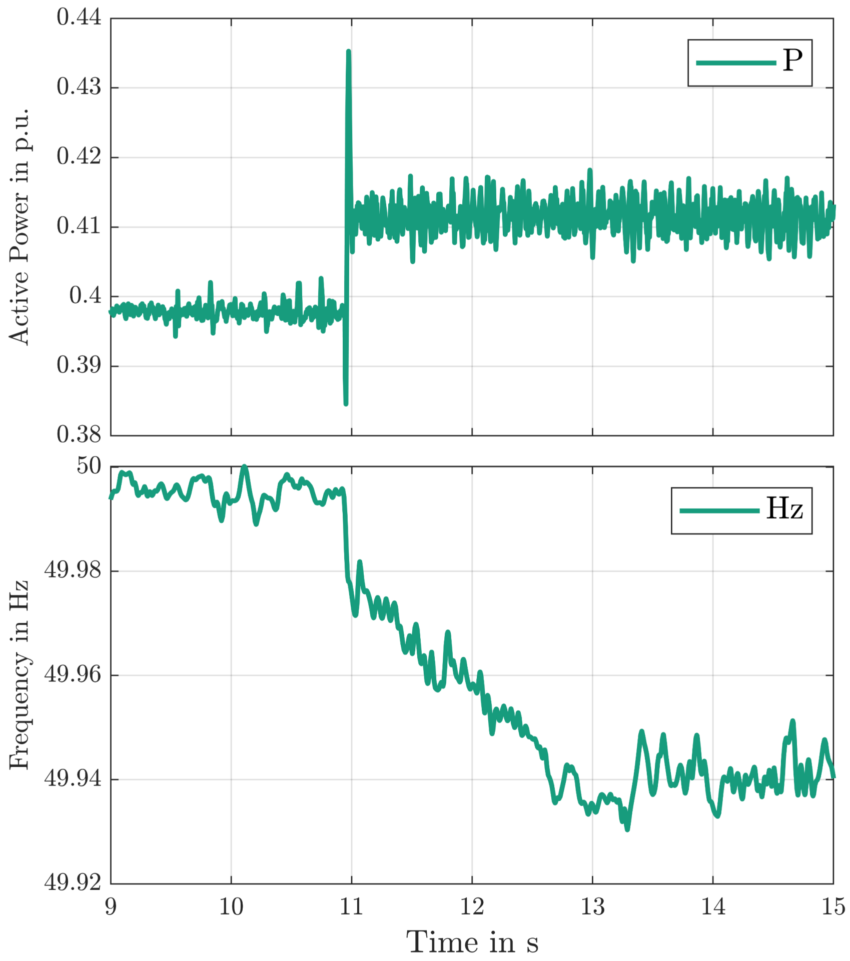
Testing results with a multi-MW BESS as test specimen

From parallel operation to islanding with similar load





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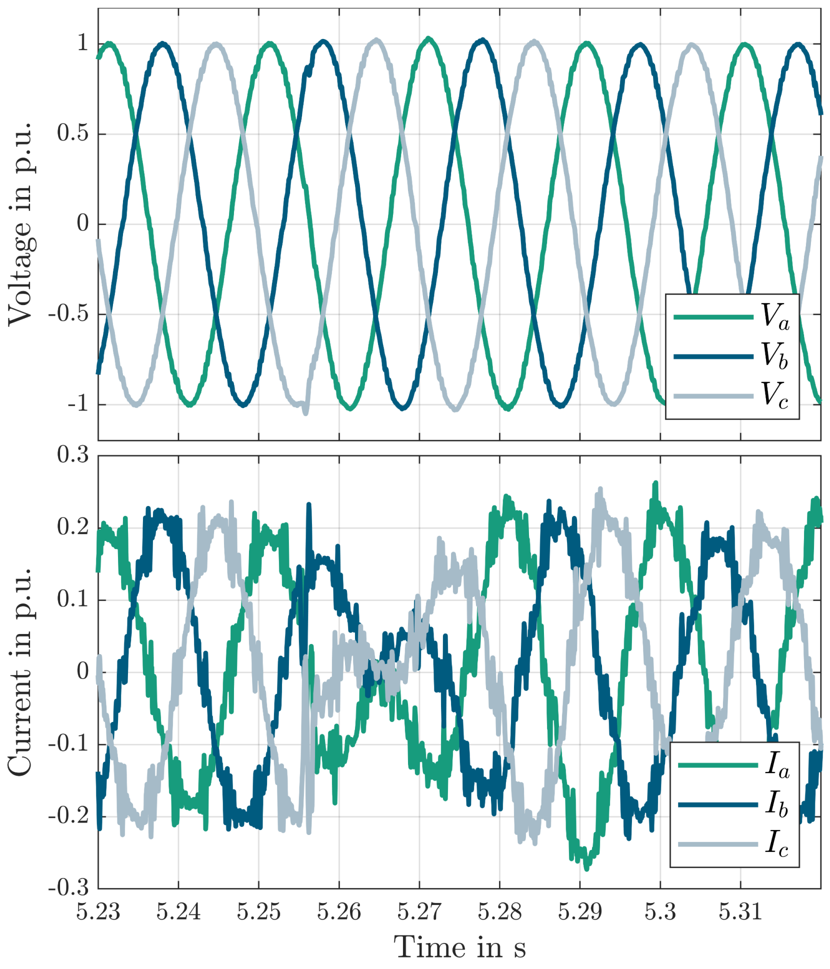
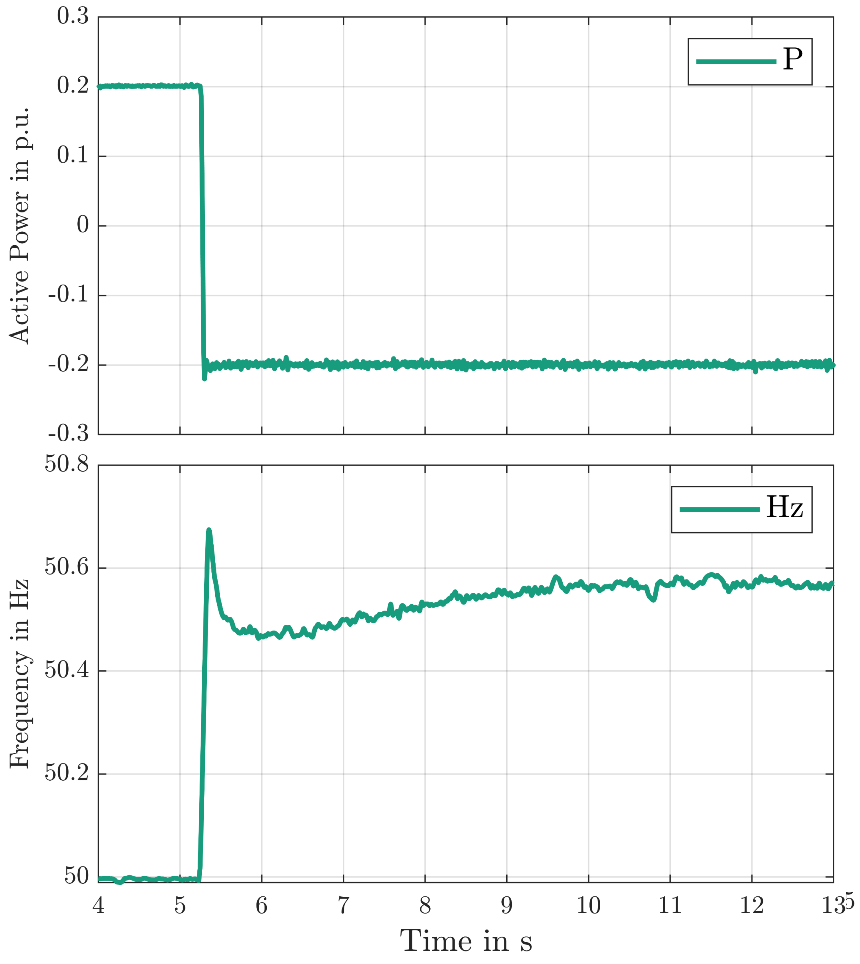
Testing results with a multi-MW BESS as test specimen

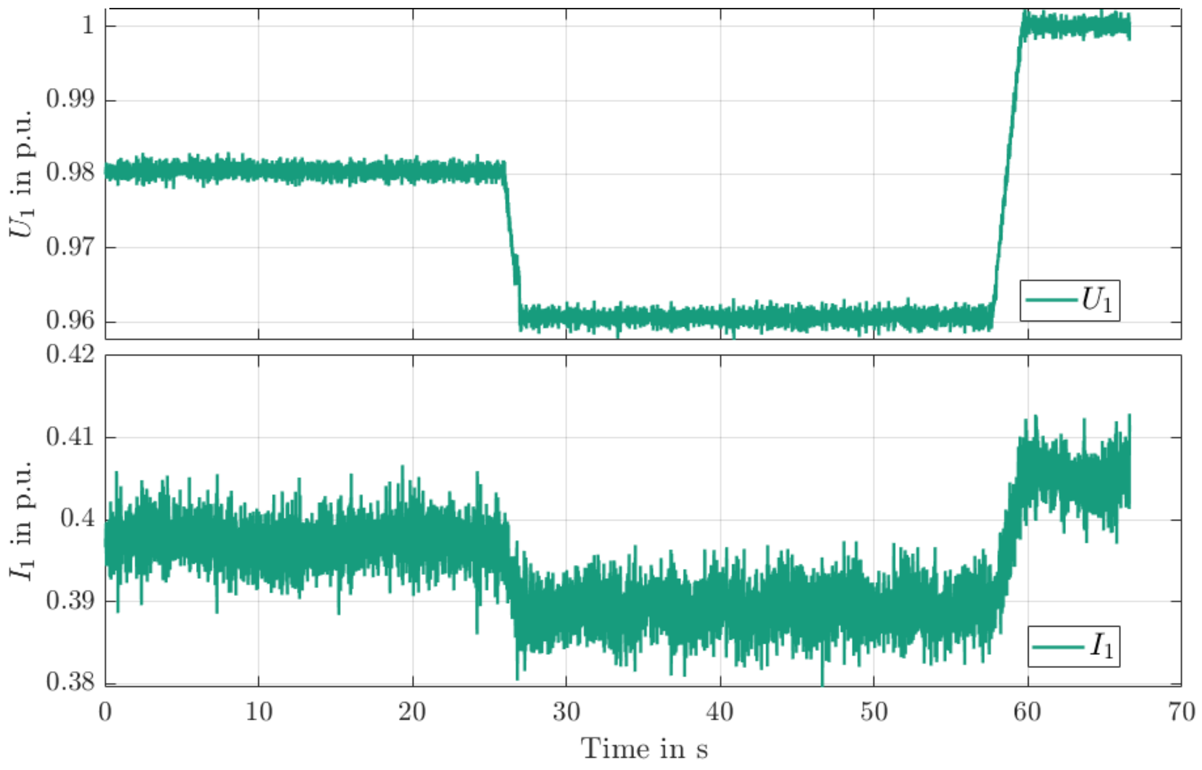
From parallel operation to islanding with a feeder (power source)

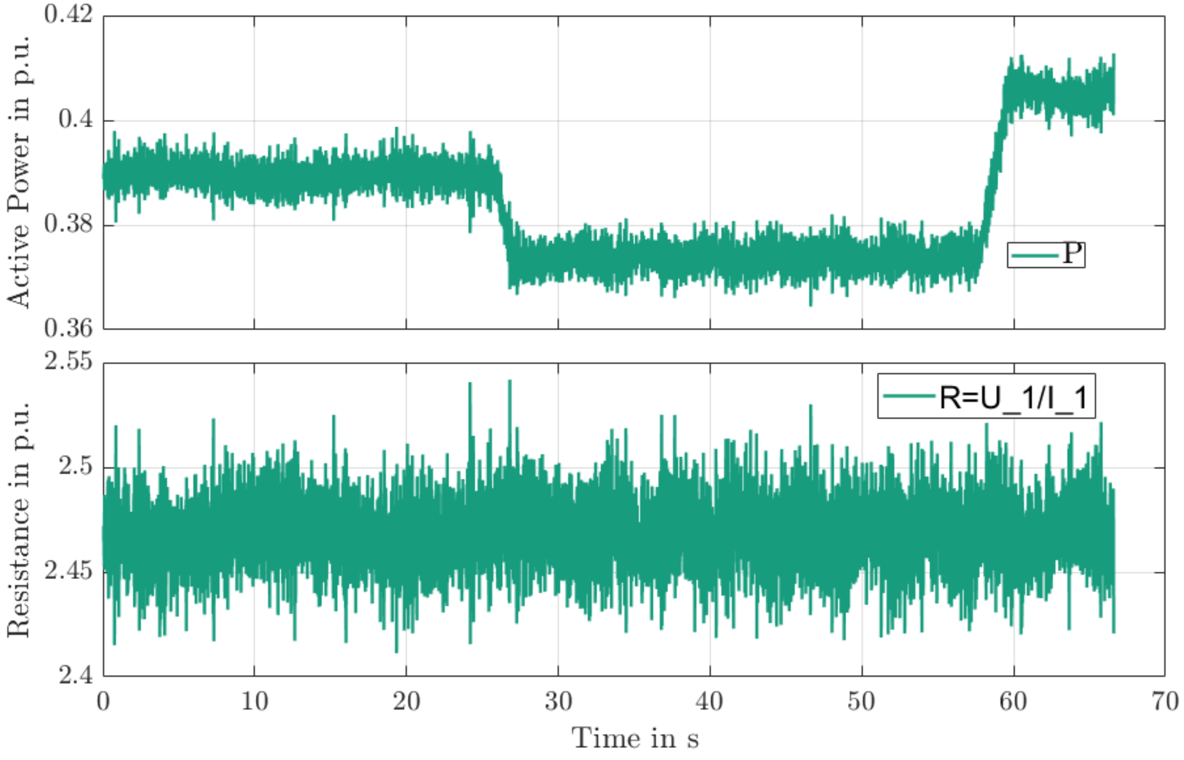




Verification of ohmic load emulation

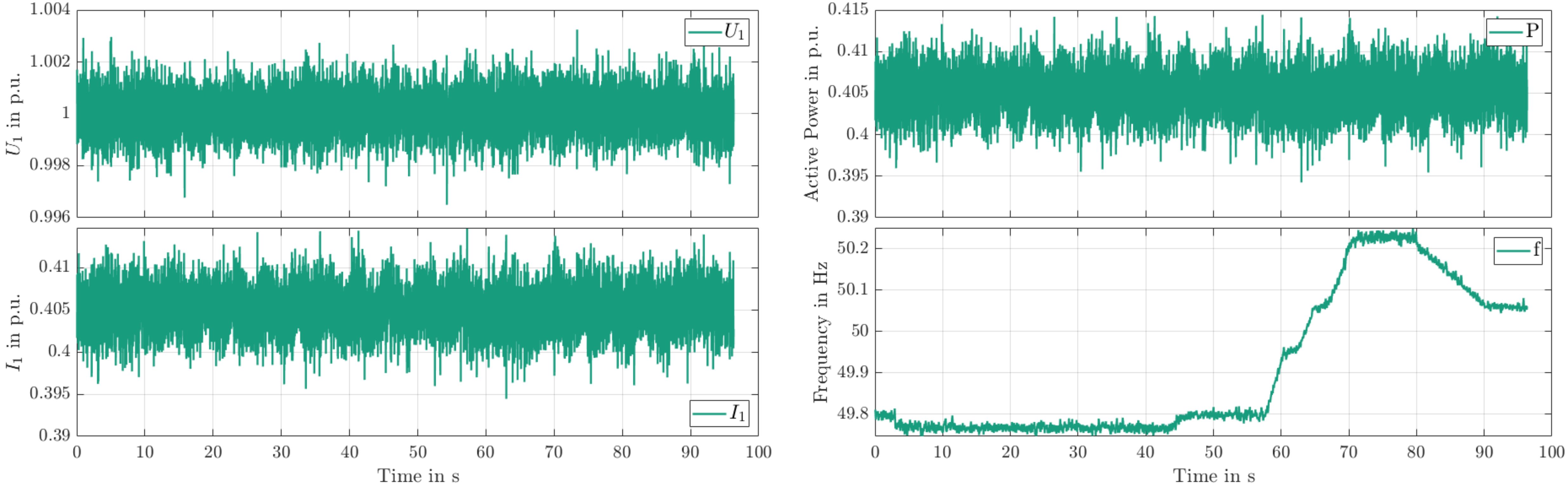
Behavior in case of changes in reactive power setpoint Q_0 with $V - V_0 = K_Q(Q - Q_0)$





Verification of ohmic load emulation

Behavior in case of changes in active power setpoint P_0 with $f - f_0 = K_P(P - P_0)$



Conclusion and Outlook

Islanding testing with Mobile Grid

Summary and lessons learned

- Commissioning of current-controlled grid emulator
- Testing with current-type PHIL setup works and shows the desired behavior
  - Careful setting of current control (settling time and damping)
- Strategy for transitioning from islanding to parallel operation should be considered from the beginning
  - Prevention of divergent frequencies and phase jumps

Next steps

- Share experiences with testing on xHIL test benches in committees
- Further development of grid-forming tests beyond island operation
  - Review and testing of the applicability of the FNN guidance document for wind turbines (type III and type IV)
  - Development of consistent validation process for wind turbines
  - Validation of testing results (with field measurements)

Requirement	
Section	**Title**
4.2.1.1	Behaviour of voltage sources
4.2.2.2	Response during underfrequency and overfrequency ranges (PCNB) – limited setting range
4.2.1.1	Active power response to a phase angle step
4.2.1.1	Effective impedance
4.2.1.2	Damping behaviour above 10 Hz
4.2.1.4	Continuous voltage control – Setpoint response
4.2.1.4	Continuous voltage control – Behaviour during disturbances and linearity of the effective impedance
4.2.1.5	Robustness through short-term over- and undervoltage events (OVRT/UVRT robustness)
4.2.1.1	Behaviour at the current limits
4.2.1.4.5	Behaviour when resuming a value within the voltage range
4.2.1.6	Fast protection during high during high voltages
4.2.1.9	Response to steep frequency gradients (RoCoF)
4.2.1.10	Capability of parallel network operation
4.2.1.11	Damping of power-frequency-oscillations (0.05 Hz – 10 Hz)
4.2.1.12 + 4.2.1.13	Provision of inertia (TA)
4.2.2.2	Behaviour in the underfrequency and overfrequency ranges (PCNB) – limited setting range

Source: VDE FNN*: Technical requirements for grid-forming capabilities including provision of inertia - Requirements and verifications for grid-forming units*, Version 2.0, English version, October 2025

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