Nordex Group

Use of Advanced Test Benches for Wind Turbine Testing

Javier Guembe
06/2026

Agenda

1 The Certification Challenge

2 Testbench Testing

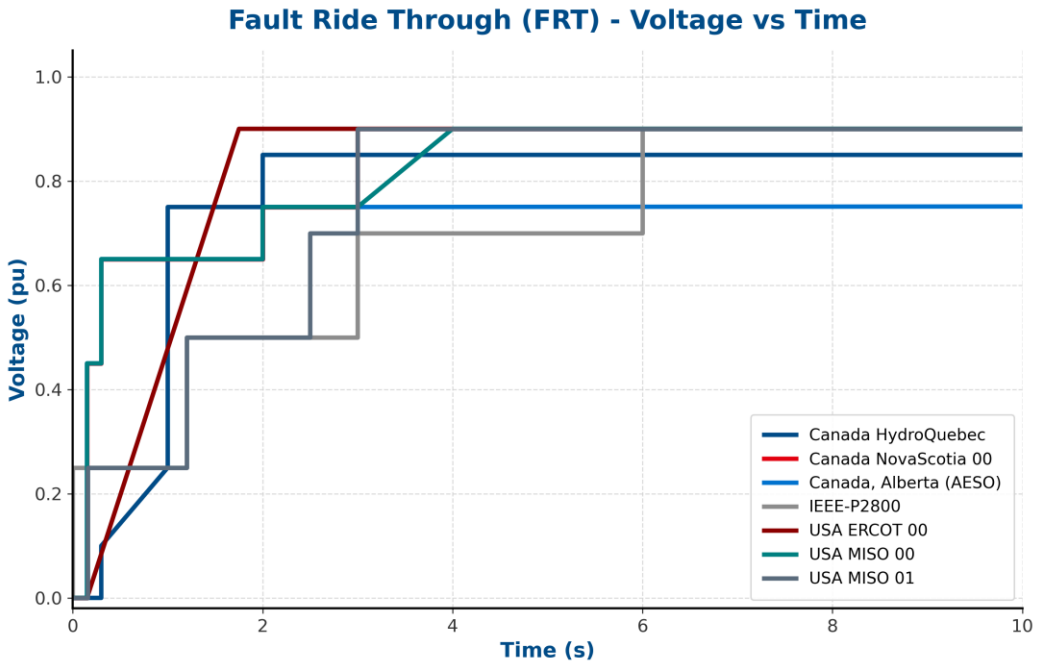
3 Validation Results

4 Conclusion

The Global Certification Challenge

GRID CODE REQUIREMENTS

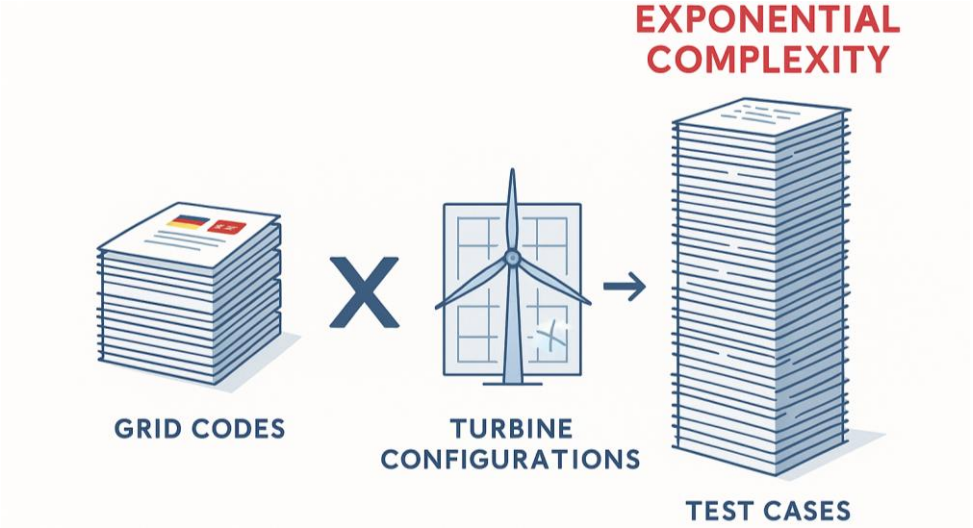
- *Distinct global requirements*



VARIANTS

Permutations of the following components:

- *Hardware: generators, converter providers, rotors, transformers, power modes*
- *Software: Turbine control, converter firmware and parametrization, protections*



Goal: Move from field testing to other controlled and rapid alternatives.

Validation Strategy for Wind Turbine Grid Compliance

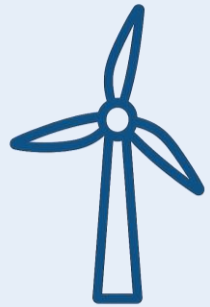
› TRADE-OFF BETWEEN COST AND DEVELOPMENT SPEED

Cost & Time

SIL

HIL

TEST BENCH



FIELD TEST

All validation levels are required to balance speed and cost

Advantages of Test Benches vs. Field Testing

› TEST BENCHES ENABLE RAPID ITERATION AND PRECISE SIMULATION

	Field tests	Test bench tests
Campaign Duration	1–2 Years (Wind-dependent)	1–2 Months (Controlled)
Components	Full hardware	Some parts simulated (Depending on testbench type)
FRT Configuration	Slow (Manual hardware setup)	Fast (Software parameter changes)
Voltage dependent Reactive Power	Grid voltage cannot be influenced sufficiently. Limited to Nominal range only.	Full capability testing (PQV)
Phase Jumps	Inexact (Hard to hit targets)	Precise (Directly forced by emulator)
SCR Changes	Weak SCR on field needed because of grid operator requirements.	Precise (Directly forced by emulator). More SCR variant possible.
Freq. & RoCoF	Impossible (Cannot alter grid)	Fully controllable
Grid-Forming	Highly limited	Full compliance ready

Strategic Transferability: IEC 61400-21-1 (Annex F)

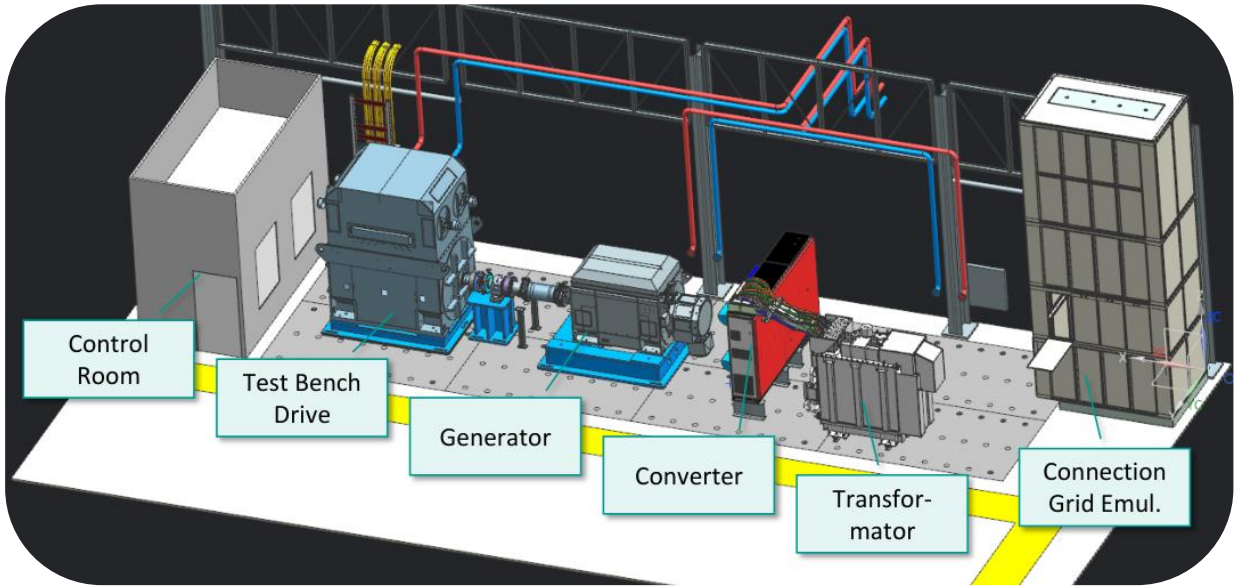
REDUCING THE EXPONENTIAL TEST MATRIX THROUGH SYSTEMATIC RISK ASSESSMENT

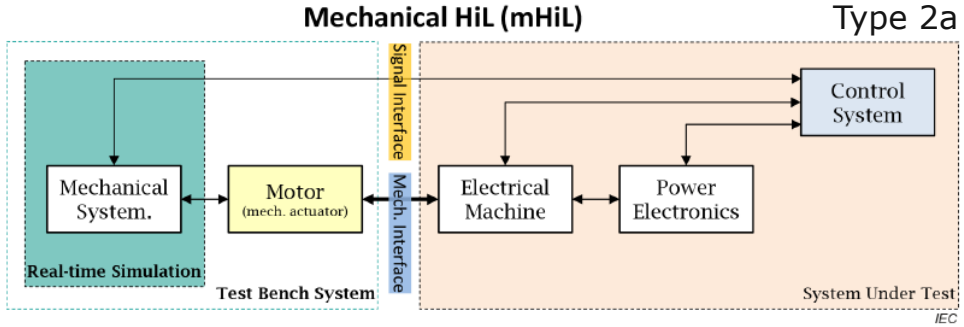
- Annex F Key Criteria:
  - Variants must belong to the same product family.
  - Power Tolerance: Nominal power rating variation ≤±25%
  - Must share identical main electrical components and control schemes.

Component	Impacted tests according to IEC	IEC Conditions for Transferability
Control	Flicker/Harmonics Switching Power/Freq control Reactive/Max power Under/overvoltage	Control: Same software and same controller hardware Parameters: Only changes in parameters affecting the power rating are accepted.
Aerodynamic	Flicker	Different rotor/hub/blades Same pitch system
Mechanical	None	Different gearbox
Generator & Converter	Reactive power Harmonics Higher frequencies	No differences
Electrical Equipment	Flicker/Harmonics Interharmonics Higher frequencies Reconnection time	No differences
Grid Protection	Grid protection	No differences

Test Bench: Fraunhofer IWES Lab

HARDWARE TEST BENCH COMPONENTS

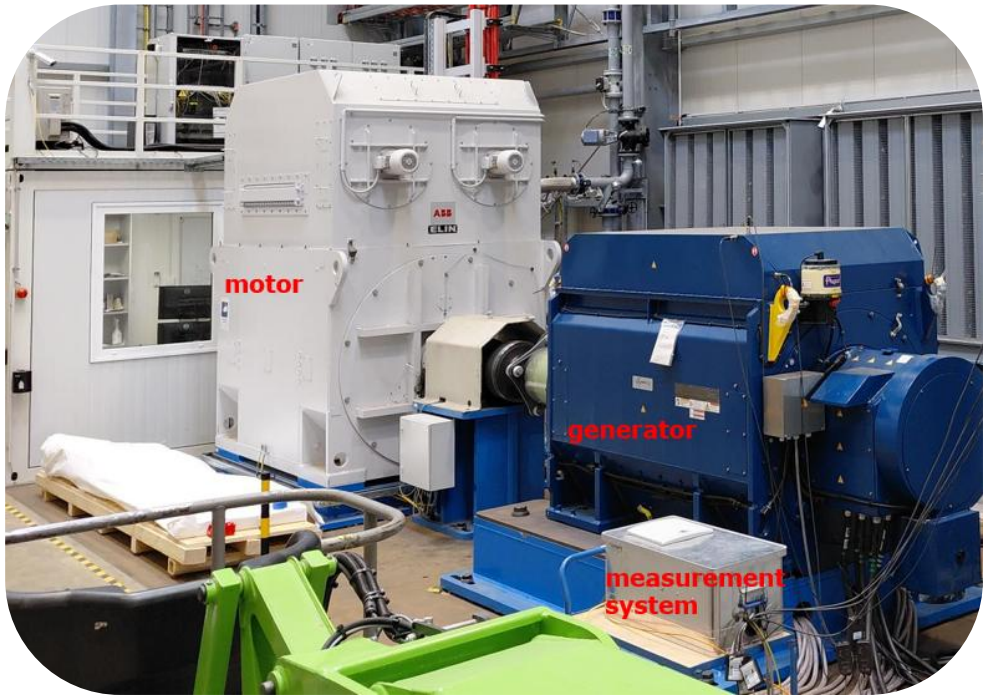


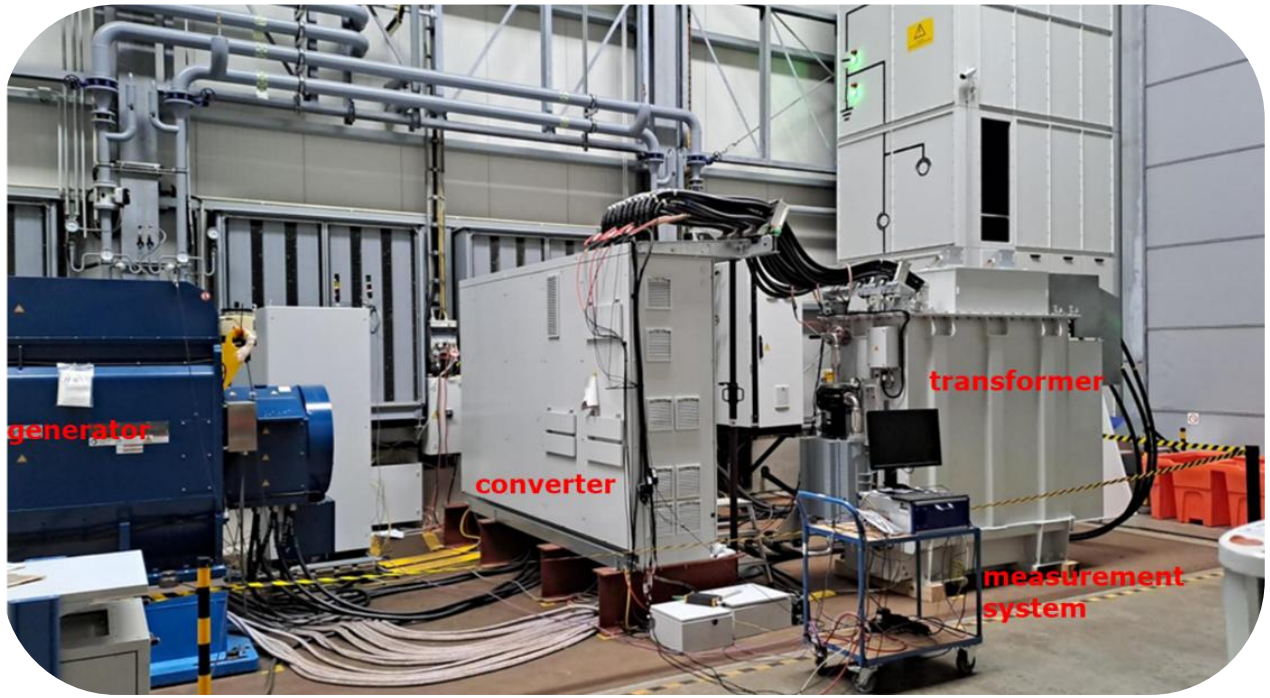


- Location:
  - Bremerhaven, Germany
- Specifications:
  - Rated power: 9MW (150% overload)
- Lab equipment:
  - Motor Drive (Blades and hub)
  - Generator
  - Converter
  - Transformer
  - Grid Emulator
- Tests:
  - Undervoltage
  - Overvoltage up to 150%
  - Frequency 45-65Hz
  - Phase Shift
  - Power Quality (possible but measurement in public grid preferred instead on grid emulator)

Test Bench: Fraunhofer IWES Lab

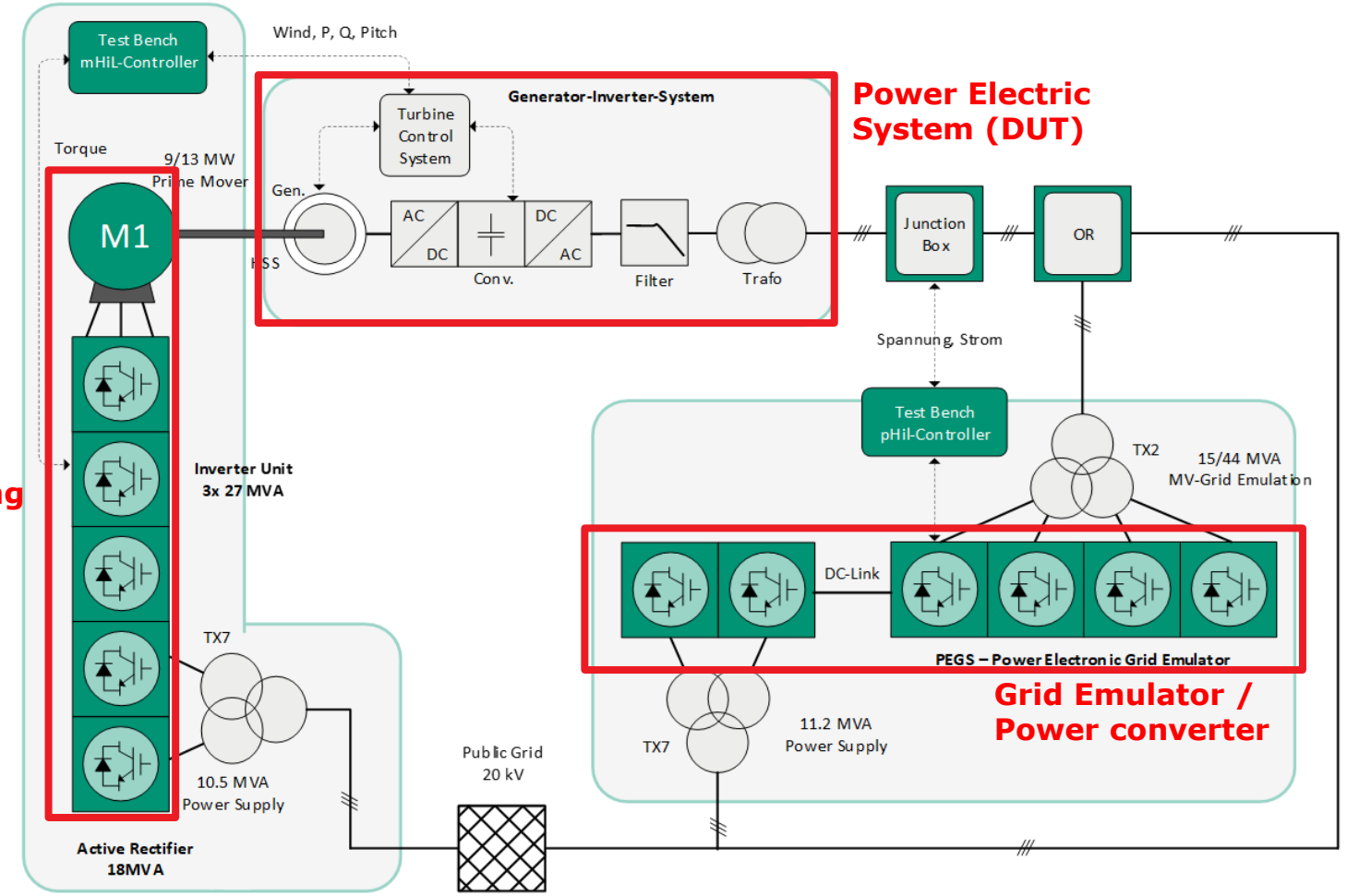
HARDWARE TEST BENCH COMPONENTS





Test Bench: Fraunhofer IWES Lab

POWER FLOW OVERVIEW



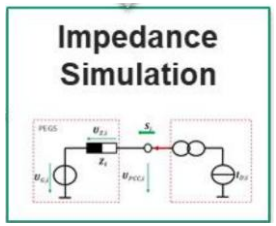
Power Electric System (DUT)

Motor/Drive which is turning the generator

Grid Emulator / Power converter

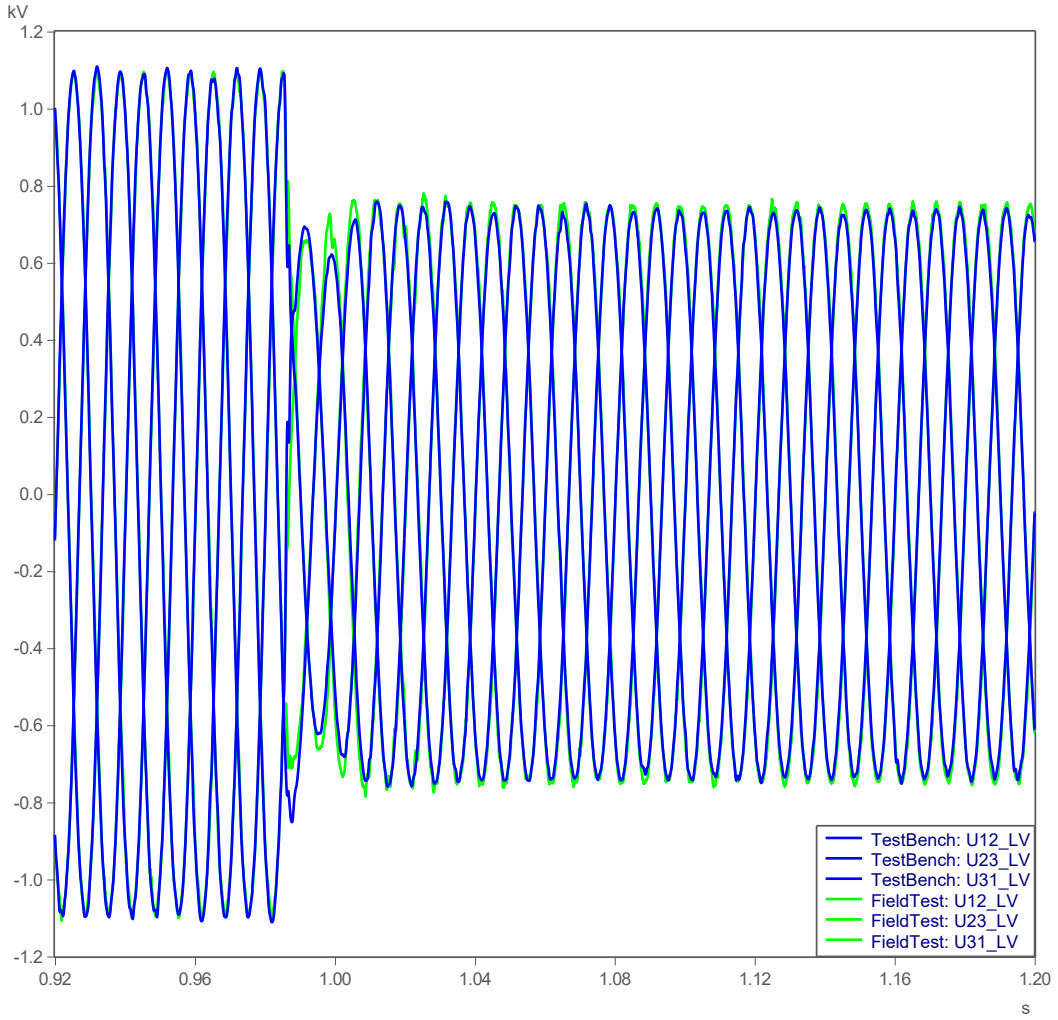
Grid Emulator:

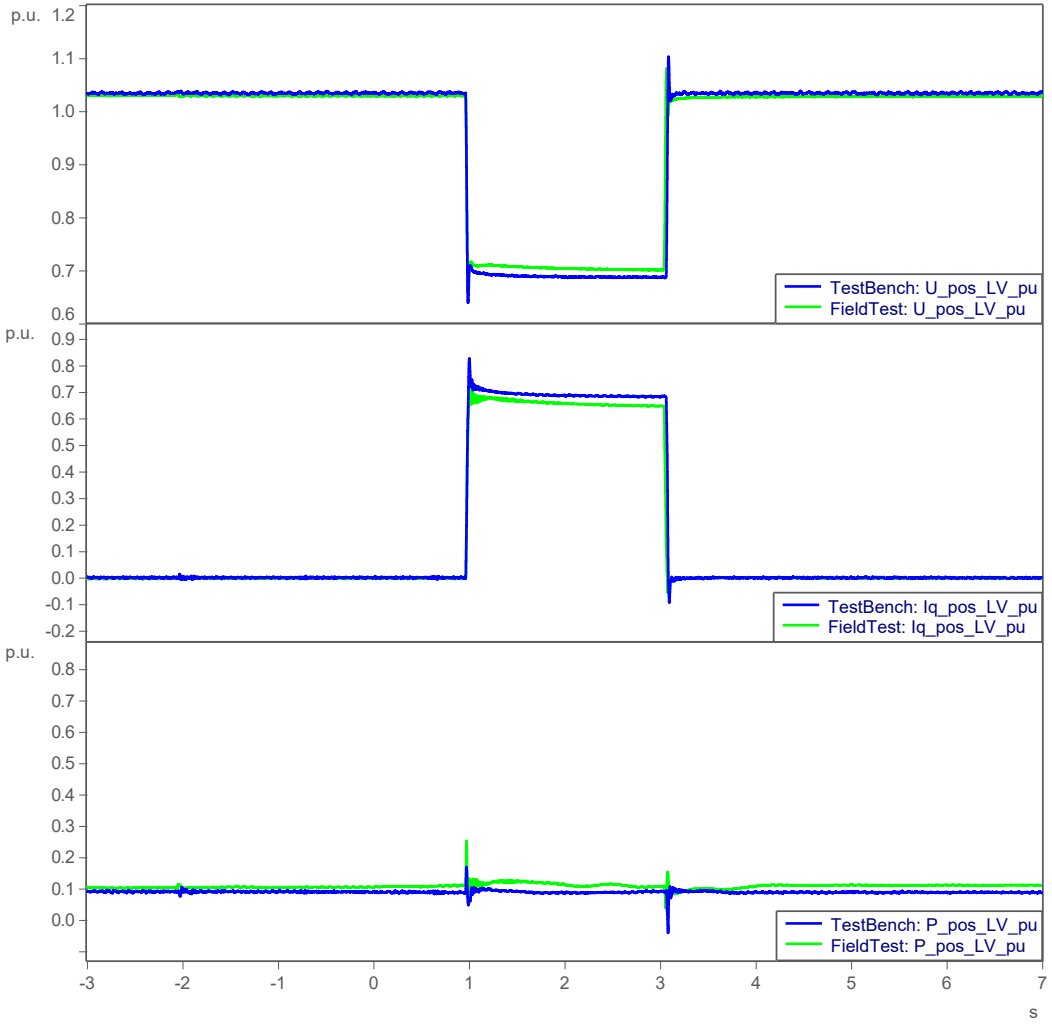
- Full converter system with Grid-Forming Control.
- Precisely generates voltage and frequency transients (FRT, phase jumps, etc.) independent of actual grid conditions.
- Continuous Power 15 MVA
- 44 MVA installed inverter power for transient events



Validation

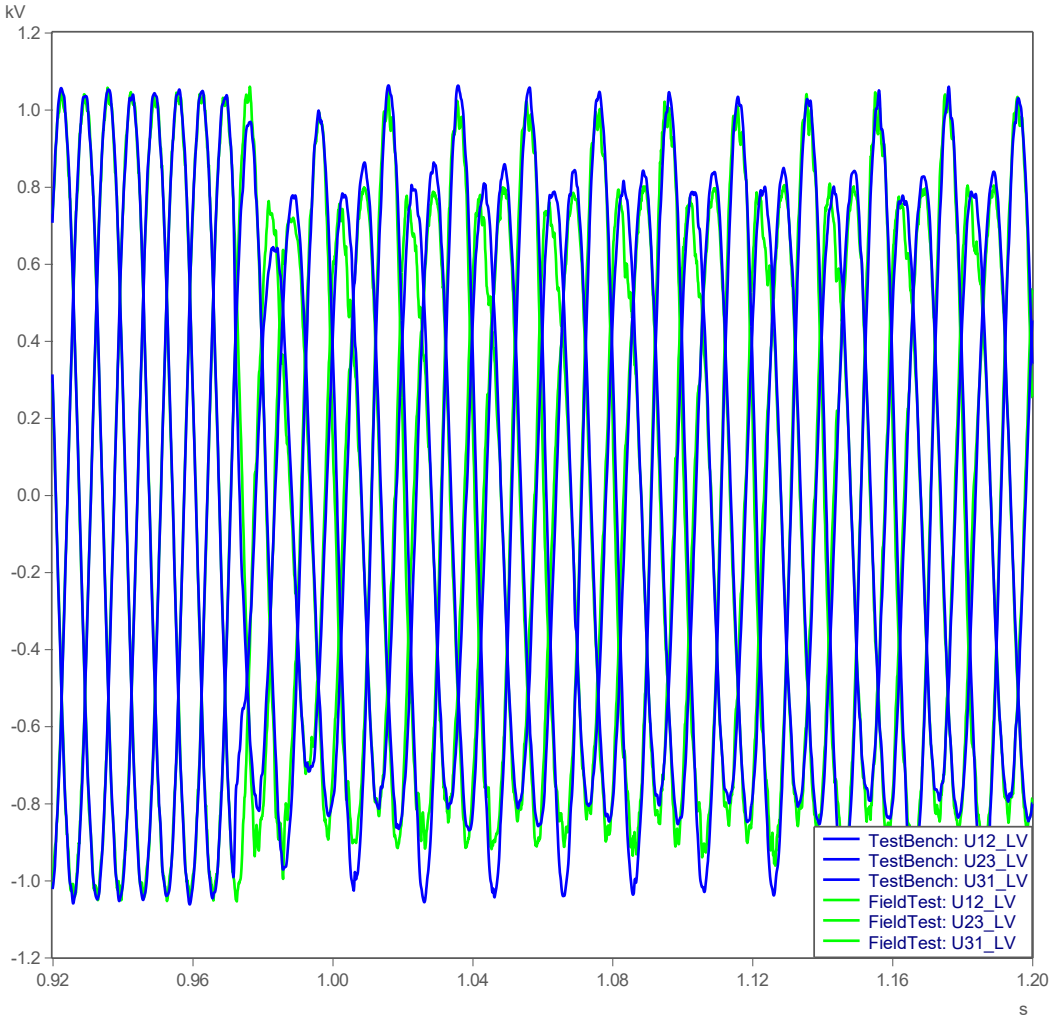
FAULT RIDE THROUGH – SYMMETRICAL FAULT 50%

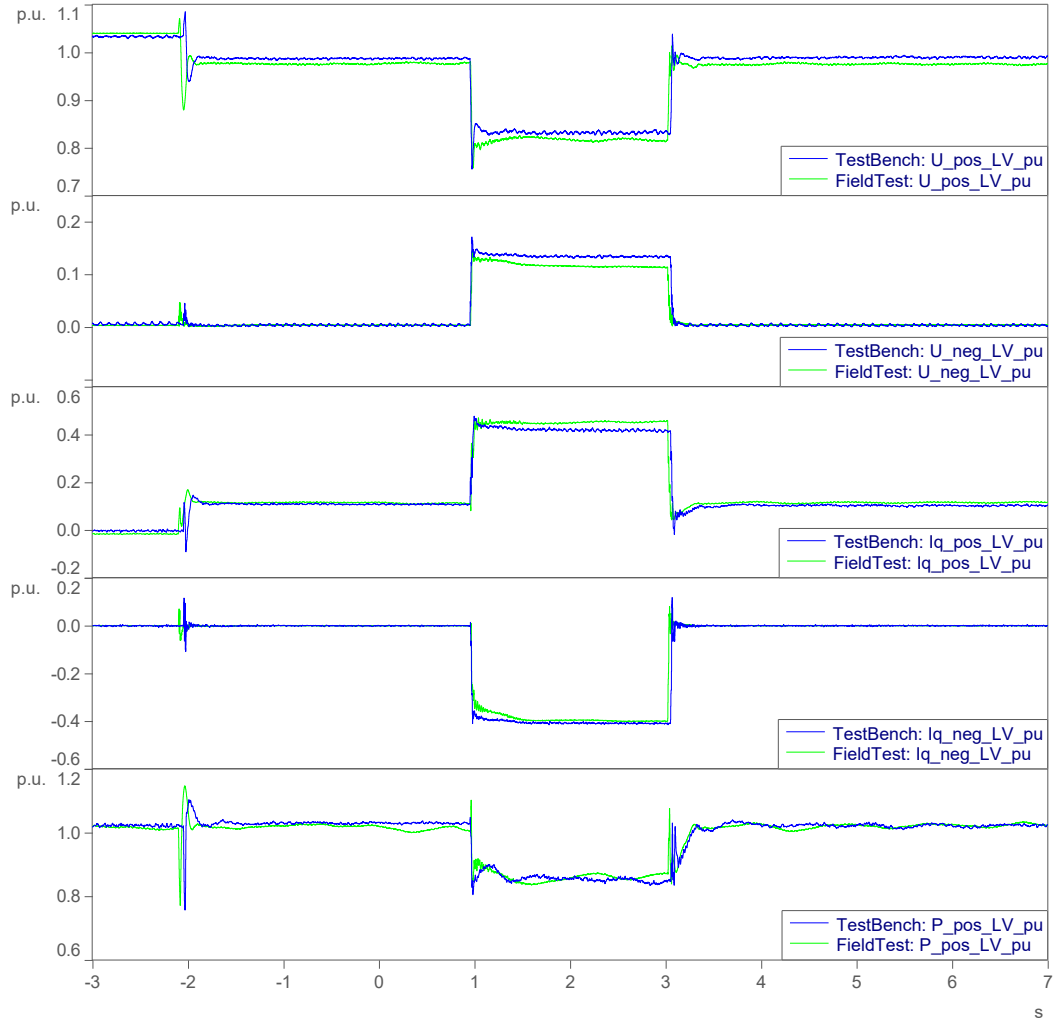




Validation

FAULT RIDE THROUGH – ASYMMETRICAL FAULT 50%

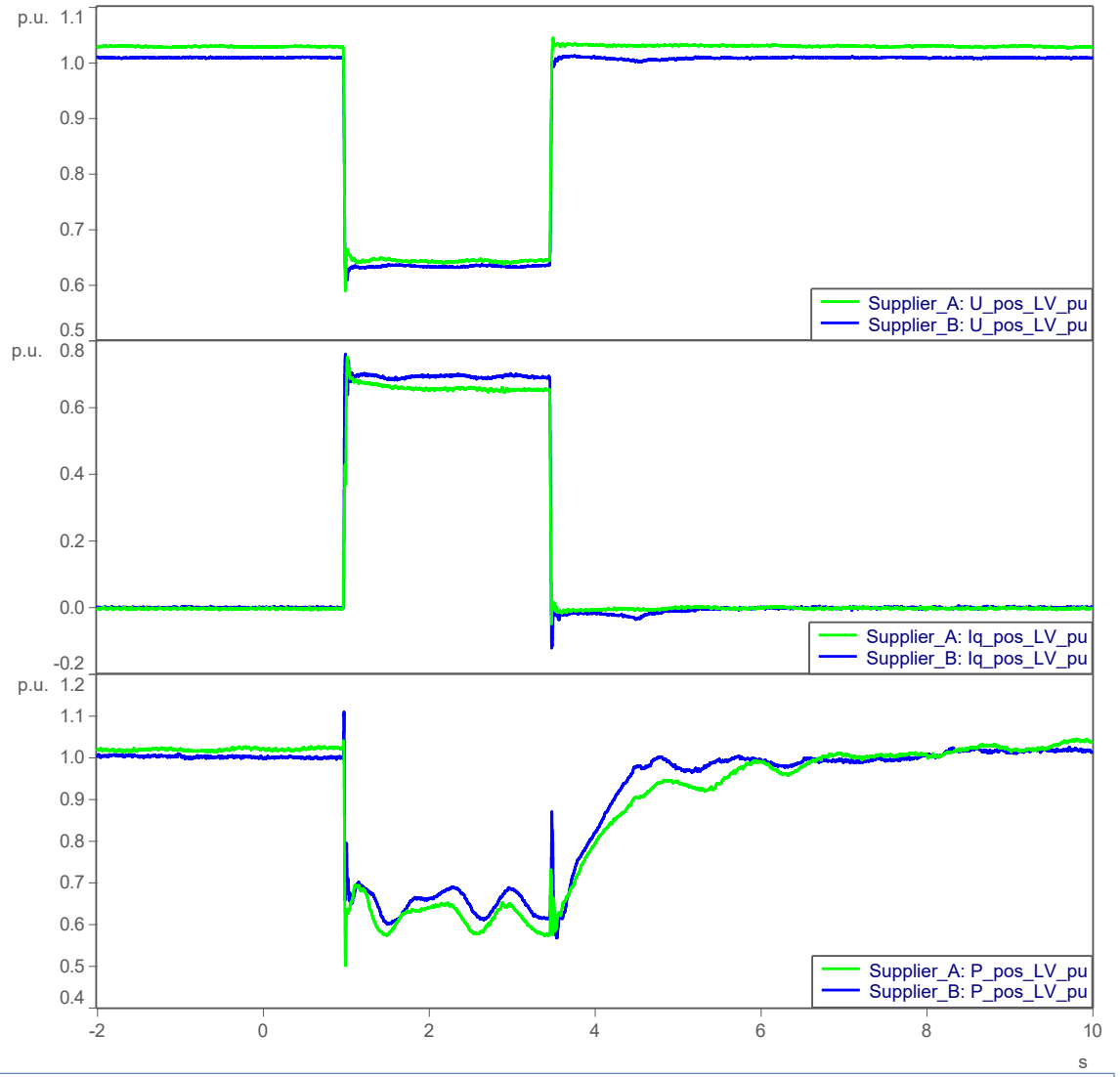




After validation - Component Interchangeability

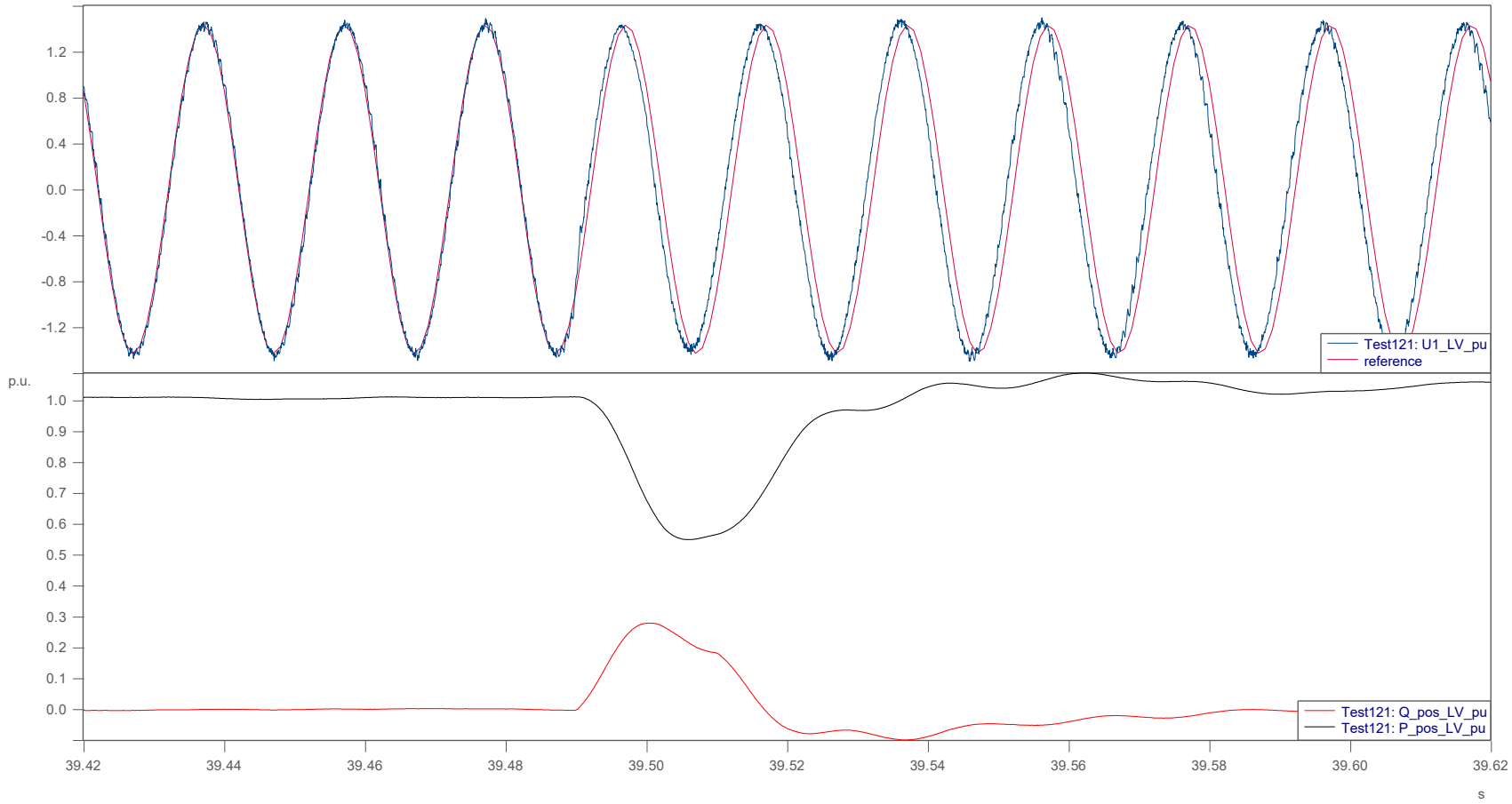
50%UN 3PH FAULT WITH 2 DIFFERENT SUPPLIERS

- Once the test bench is validated, it serves as a certified baseline for the turbine platform
- We can test alternative main components (e.g., converters from different suppliers) against this baseline.



20° Phase Jump

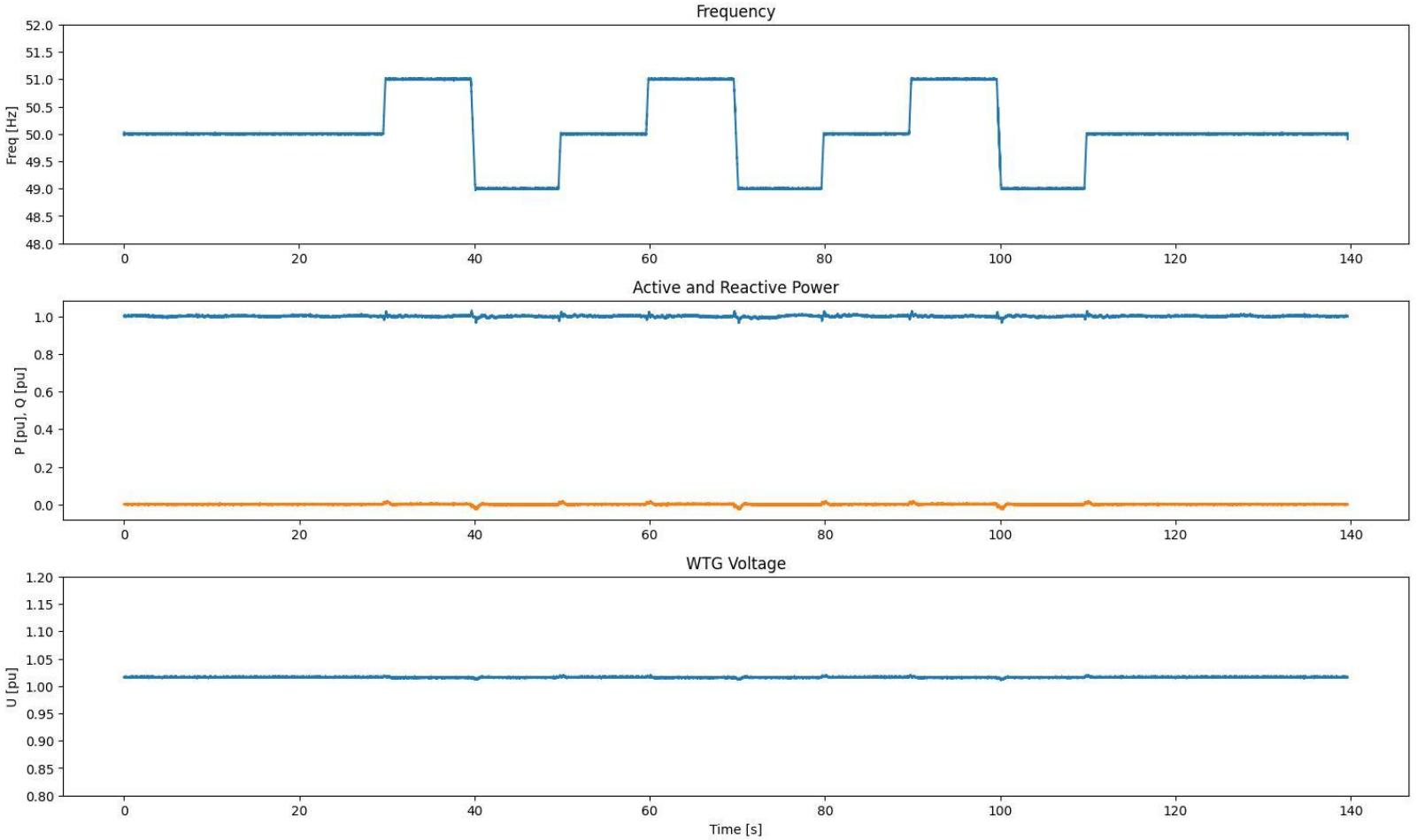
› PHASE JUMP 20º



Phase jumps are created by directly forcing the phase jump in the output voltage of the grid emulator. Exact values can be configured.

Frequency profile

› FREQUENCY OPERATION RANGE OF THE TURBINE



The frequency is directly controlled and modified in the output voltage of the grid emulator.

Conclusions

1. Overcoming the Testing Bottleneck

- The use of testbenches can drastically reduce test time and resolves the exponential test matrix.

2. High-Fidelity Event Validation

- Test benches are able to validate critical capabilities—like precise Phase Jumps and high RoCoF, that are almost impossible to safely replicate on real grids.

3. Strategic Certification

- We can conduct component testing once, and systematically transfer those results across identical product families, saving resources.

Thank you for your attention