FAU Friedrich-Alexander-Universität
Lehrstuhl für
Elektrische Energiesysteme

success story



Image courtesy of Statkraft

De-risking grid code compliance for a 50 MW grid-forming BESS.

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) uses CHIL simulation to enable early validation of grid-forming controls and help identify compliance risks before deployment.

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A utility-scale grid-forming BESS project.

Grid-forming battery energy storage systems (BESS) are becoming critical enablers of power system decarbonization, providing voltage and frequency support that was traditionally delivered by synchronous generation.

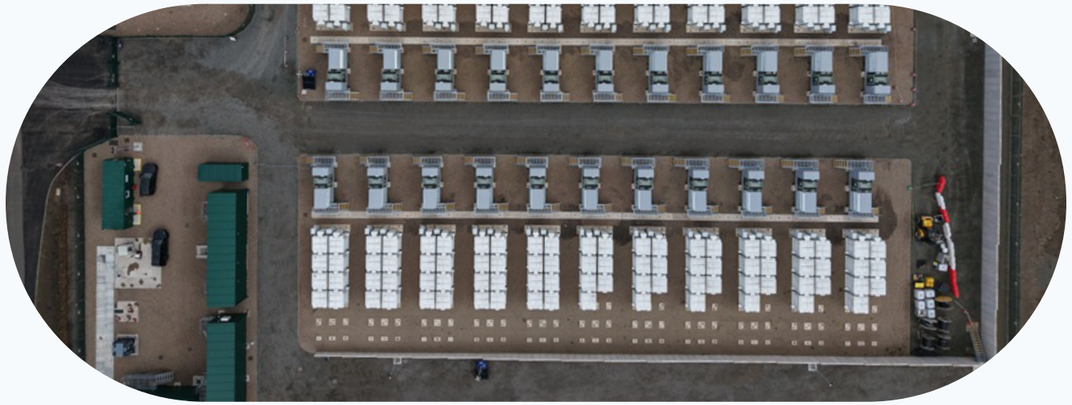


Image courtesy of Statkraft

As their role grows, so do the grid code requirements they must satisfy before connecting to the transmission network.

This success story highlights the **Neilston Greener Grid Park, a 50 MW grid-forming BESS** validated against the UK Grid Code requirements in effect at the time. Compliance testing was discussed with the **National Energy System Operator (NESO)**, which also received the final report. To the partners' knowledge, this was the first grid-forming BESS project to undertake comprehensive grid code compliance validation using CHIL simulation. Real-time simulation and CHIL testing were led by the **Institute for Electrical Energy Systems at Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)**, which bridges academic research and industrial practice. The work was conducted in close collaboration with **Fluence Energy GmbH**, a global leader in energy storage technology and the project's BESS supplier and power plant controller developer.

The multi-vendor project brought together Fluence, FAU, NESO, Statkraft, and converter manufacturer SMA. Together, **the partners validated the complete BESS, including its power plant controller (PPC) and associated control infrastructure, against stringent grid code requirements before commissioning, helping reduce technical, scheduling, and integration risks.**

De-risking grid code compliance before commissioning.

The main challenge was to validate the grid code compliance of the complete Neilston Greener Grid Park BESS, including its Power Plant Controller, in an efficient and flexible manner. Many grid code compliance tests **require deliberate grid disturbances**—such as voltage magnitude variations, frequency deviations, or phase-angle changes—that are **impractical or impossible to create on a stiff utility grid or during normal plant operation.**

CHALLENGES

Traditional field-based validation presented several challenges:

- ✖ Limited flexibility when requirements or controller parameters evolve during development
- ✖ High costs associated with repeated site testing campaigns
- ✖ Long feedback cycles between development, integration, and validation teams
- ✖ Difficulty reproducing severe grid disturbances in a controlled and repeatable manner
- ✖ Increased project risk due to the late discovery of control and integration issues

REQUIREMENTS

The validation platform for this project needed to:

- ✔ Test the complete control architecture, including the actual PPC hardware
- ✔ Reproduce demanding grid code scenarios safely and repeatably in the laboratory
- ✔ Run high-fidelity EMT models of the converter and network in real time
- ✔ Support automated, scriptable test execution for large campaigns
- ✔ Remain flexible as requirements and controller parameters evolve

Controller hardware-in-the-loop testing with HYPERSIM.

To de-risk grid code compliance and accelerate project validation, the team implemented a comprehensive CHIL testing platform based on HYPERSIM.

At the core of the solution was a high-fidelity electromagnetic transient (EMT) model of the power system and converter infrastructure, running in real time on OPAL-RT simulation hardware.

A detailed switching converter model was developed in HYPERSIM in close collaboration between converter manufacturer SMA and OPAL-RT, and benchmarked against the real device to accurately capture converter dynamics—keeping the simulation very close to the hardware that would later be deployed in the field.

Rather than emulating the measurement unit that communicates PCC measurements to the Power Plant Controller, **the physical measurement hardware was connected directly to the real-time simulation**. This avoided errors introduced by pure software emulation and ensured the setup closely represented the final field implementation.

The platform integrated the actual PPC, physical measurement hardware, and converter control implementations, **enabling realistic testing of the complete control chain under representative operating conditions.**

CHIL BENEFITS

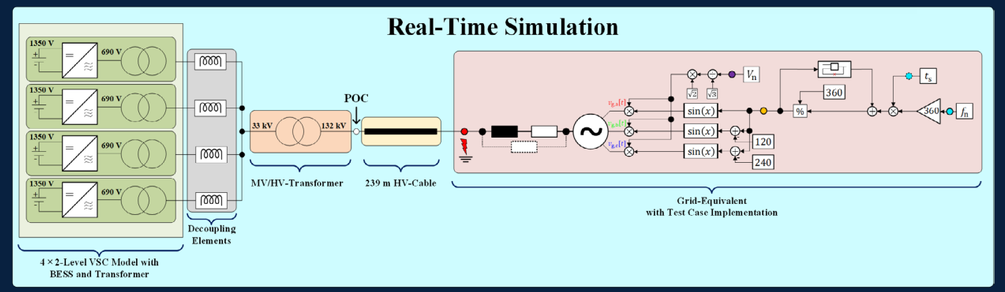
Unlike software-only approaches, the CHIL environment incorporated the actual hardware interfaces used in the final deployment, allowing engineers to evaluate interactions between:

- The Power Plant Controller (PPC)
- Measurement and communication equipment
- Converter control systems
- The simulated transmission network

This architecture enabled demanding grid code test scenarios to be **reproduced consistently in a controlled and fully repeatable laboratory environment**, without requiring access to a live transmission grid.

HYPERSIM's Python API allowed the development team to automate the entire testing workflow.

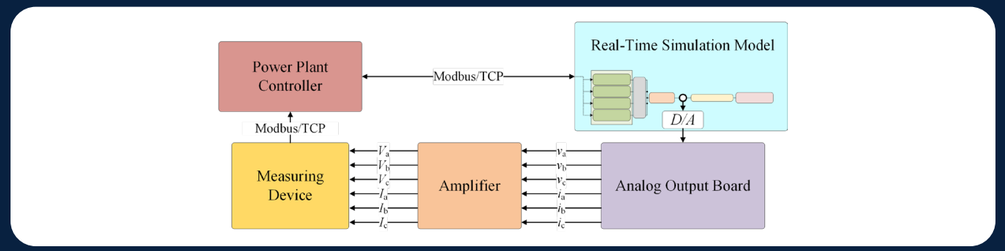
Through automated scripting and a custom graphical user interface built on top of the simulation, even non-expert users could execute standardized test sequences **without in-depth knowledge of the underlying real-time model.**



Engineers were able to:

- Execute standardized grid code compliance test sequences
- Automatically configure simulation scenarios
- Trigger test campaigns with minimal manual intervention
- Collect and store results in a structured format
- Generate repeatable datasets for compliance reporting

The automation framework transformed what would traditionally be an expert-driven, manual process into **a scalable validation workflow accessible to non-expert users**, and **facilitated the generation of the structured results** required for the final compliance report submitted to NESO.



Earlier validation, reduced project risk.

The CHIL-based validation approach significantly reduced project risk by allowing comprehensive compliance verification to occur **in parallel with system development.** By enabling grid code compliance tests to be prepared in parallel with the ongoing development of the control system and simulation models, the workflow was substantially parallelized compared to traditional sequential testing. **This reduced waiting times between development, integration, and validation phases**, allowed faster iteration cycles, and resulted in a noticeably shorter overall project timeline and faster readiness for formal testing.

RESULTS

More than 60 test cases implemented, automated, and validated.

Reduced technical risk

Potential control and integration issues were identified earlier, reducing the likelihood of costly late-stage corrections.

Increased confidence

Validating the full control architecture under realistic conditions increased confidence in compliance readiness.

Greater test coverage

Scenarios that would be difficult or impossible to reproduce in the field could be executed repeatedly and consistently in the laboratory.

Accelerated validation workflow

HYPERSIM real-time simulation and Python-based automation reduced manual effort and enabled efficient, large-scale test campaigns.

Enhanced scalability for future projects

The reusable framework can support future grid-forming BESS developments and growing compliance-testing needs.

Read more and access the full conference paper here:

Advancing grid-forming validation with OPAL-RT technology.

The Neilston Greener Grid Park project demonstrated that CHIL simulation can serve as a highly effective approach for validating the grid code compliance of grid-forming battery energy storage systems. By enabling flexible, high-fidelity testing throughout the development process, the solution **accelerated project execution while maintaining the level of confidence required for compliance validation.**

Given the large number of grid-forming projects required to support decarbonization, FAU and Fluence see **scalable validation approaches** such as CHIL simulation becoming essential for the timely deployment of future assets.

FAU is already applying this experience in the national flagship project on grid-forming hybrid power plants (CHIMERA, funded by BMFTR), while Fluence is further expanding its HIL capabilities for grid compliance and customer acceptance testing across current and future projects.

Our project partners.



Andreas Bammes
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Andreas Bammes received his B.Sc. (2020) and M.Sc. (2022) in electrical engineering from FAU. Since 2023, he has been a Research Associate at the Institute for Electrical Energy Systems, where he leads the real-time simulation laboratory. His research focuses on the impact of pulse-width modulation on harmonic interactions in power systems and their verification using real-time simulation, with experience in hardware-in-the-loop grid code compliance validation.

Fluence Energy GmbH
Global market leader in energy storage technology and digital energy solutions

The Fluence team contributed its expertise in power plant controllers and battery energy storage systems to the project, bringing extensive industrial control-development experience to the CHIL-based grid code compliance validation.

For more information, contact Stefan Henninger, Senior Manager, PCS Controls Development.

Success story and diagrams adapted from: A. Bammes et al., “De-Risking Grid Forming Battery Energy Storage Projects - Grid Code Compliance testing of a 50 MW Storage System using Control-Hardware-in-the-Loop,” in CIGRE 2025 International Symposium, Montreal, CA, Oct. 2025.



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For over two decades, OPAL-RT TECHNOLOGIES has been a global leader in real-time simulation and hardware-in-the-loop (HIL) testing. Since 1997, OPAL-RT has empowered engineers and researchers with accessible, innovative, and customized simulation technology—bridging the gap between modeling and real-world applications. By leveraging high-performance computing, OPAL-RT accelerates the development of advanced solutions in energy, automotive, aerospace, and beyond. With our ISO 9001:2015 certification and a strong commitment to sustainable development, we're not just developing technology—we're building a better future, together.

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