National Laboratory of the Rockies

Data Center Power Systems: Megawatt-Scale Hardware Testing for Evaluating Grid-Side and Load-Side Performance

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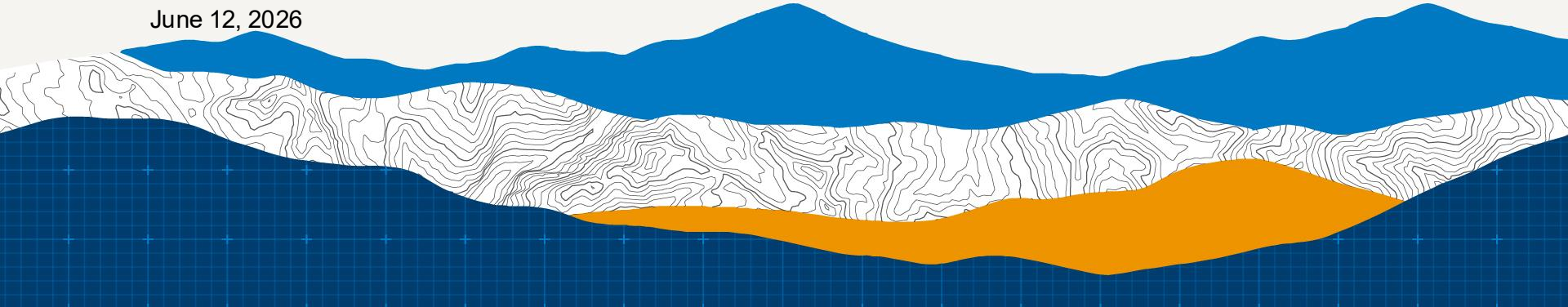
ESIG Summer Workshop: Large Load Modeling, Testing, and Interconnection Requirements

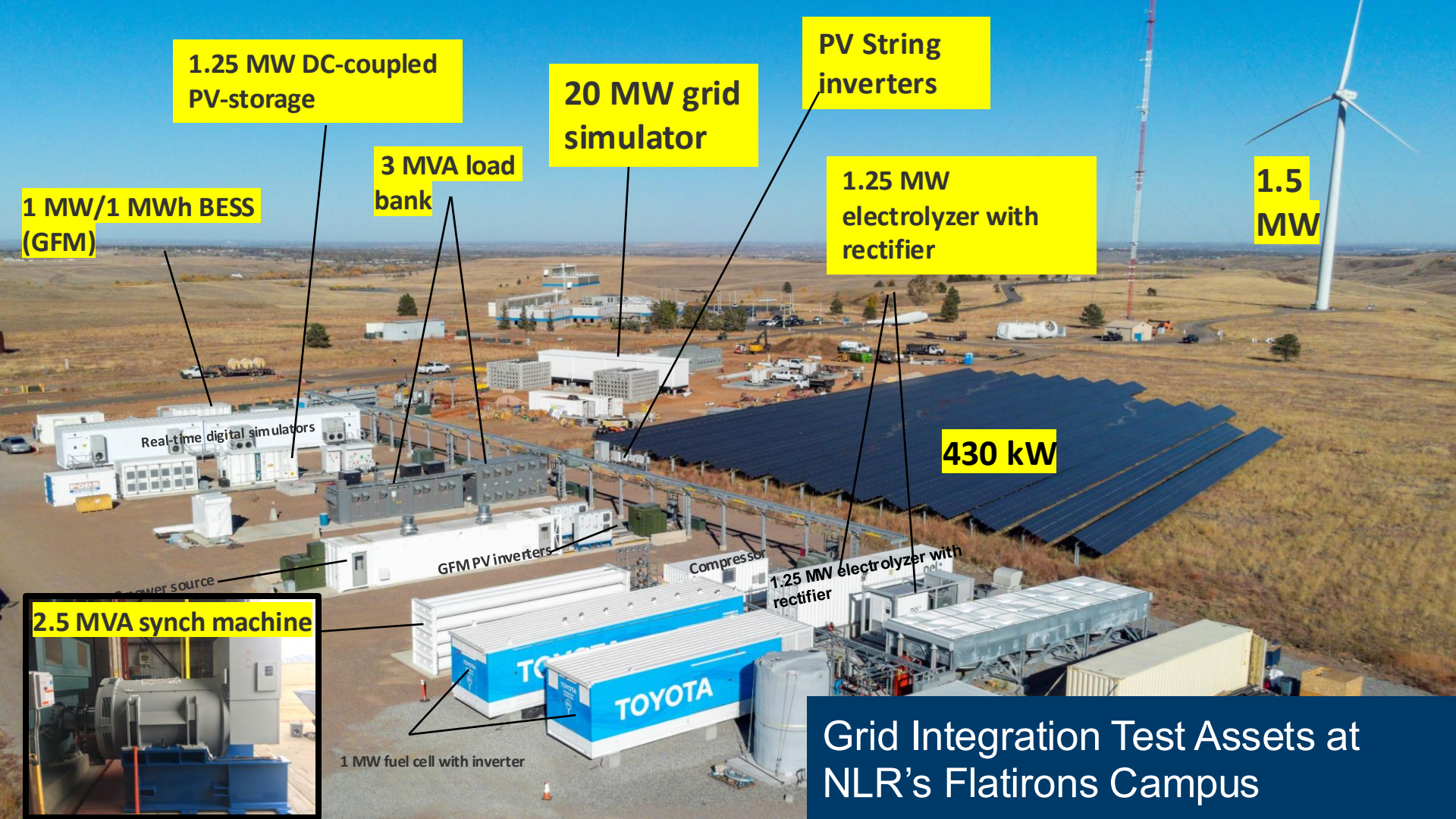
June 12, 2026



Outline

- NLR's ARIES Testbed at Flatirons Campus for Grid Integration Testing at Scale
  - Grid simulators (20 MVA and 7 MVA)
  - Medium Voltage Impedance Network (MVIN)
  - Medium Voltage Data Acquisition System (MVDAS)
  - Control Room
- Test Examples
  - AI load profile emulation
    - To evaluate compliance with load-side requirements. E.g., ITIC/CBEMA, IEC 62040-3
  - Voltage ride-through
    - To check compliance with grid interconnection requirements for large loads. E.g., NOGRR 282
  - Frequency-domain impedance scans (dq, sequence, phasor)
    - To perform stability analysis and EMT model validation

Grid Integration Testbed at NLR Flatirons Campus

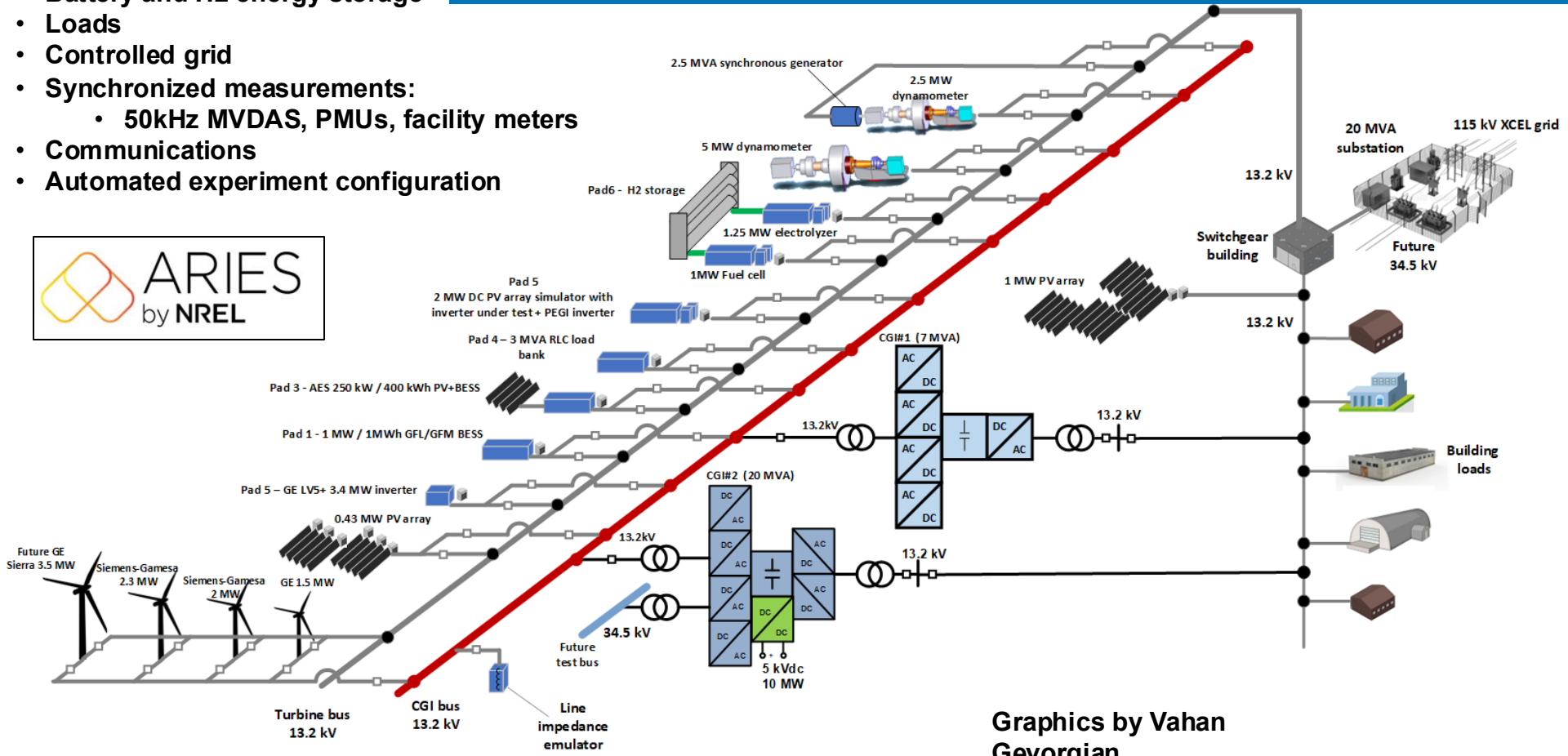


Grid Integration Test Assets at NLR's Flatirons Campus

NLR's ARIES Testbed at Flatirons Campus

- Utility-scale wind
- Utility-scale PV
- Battery and H2 energy storage
- Loads
- Controlled grid
- Synchronized measurements:
  - 50kHz MVDAS, PMUs, facility meters
- Communications
- Automated experiment configuration

ARIES by NREL



Graphics by Vahan Gevorgian

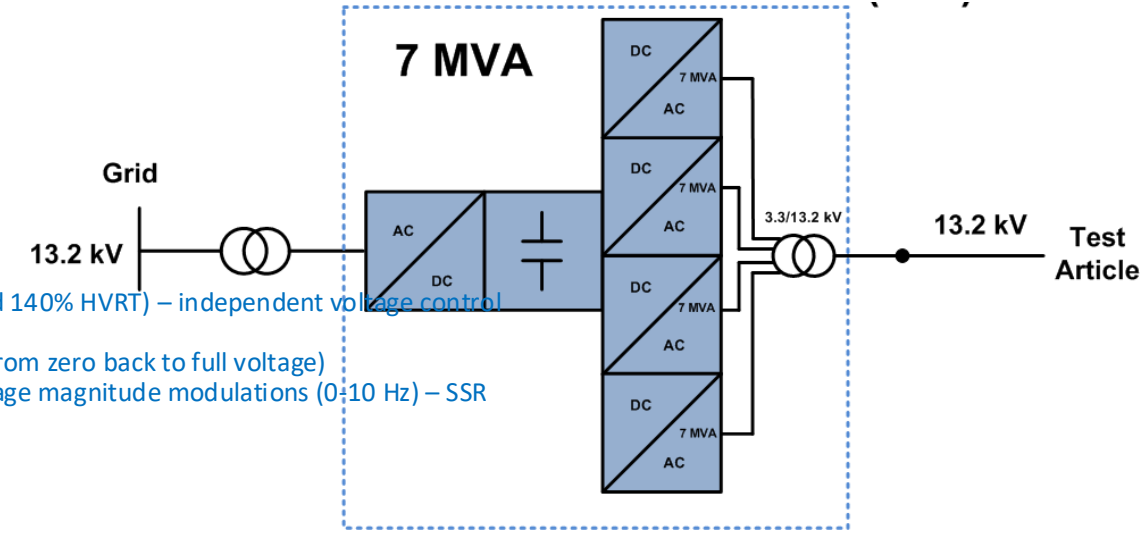
Grid Simulator #1: 7 MVA Continuous Power

Power rating
- 7 MVA continuous
- 39 MVA short circuit capacity (for 2 sec)
- 4-wire, 13.2 kV

Possible test articles
- Types 1, 2, 3 and 4 wind turbines
- PV inverters, energy storage systems
- Conventional generators
- Combinations of technologies

Voltage control (no load THD <1%)
- Balanced and un-balanced voltage fault conditions (ZVRT and 140% HVRT) – independent voltage control for each phase on 13.2 kV terminals
- Response time – 1 millisecond (from full voltage to zero, or from zero back to full voltage)
- Long-term symmetrical voltage variations (+/- 10%) and voltage magnitude modulations (0-10 Hz) – SSR conditions
- Programmable impedance (strong and weak grids)
- Programmable distortions (lower harmonics 3, 5, 7)
- Impedance characterization of inverter-coupled generation
- Full STATCOM functionality

Frequency control
- Fast output frequency control (5 Hz/sec) within 45-65 Hz range
- 50/60 Hz operation
- Can simulate frequency conditions for any type of power system
- PHIL capable (coupled with RTDS)
- Test-bed for PMU-based wide-area stability controls
- **Test article impedance scan**



Less than 1 ms response time

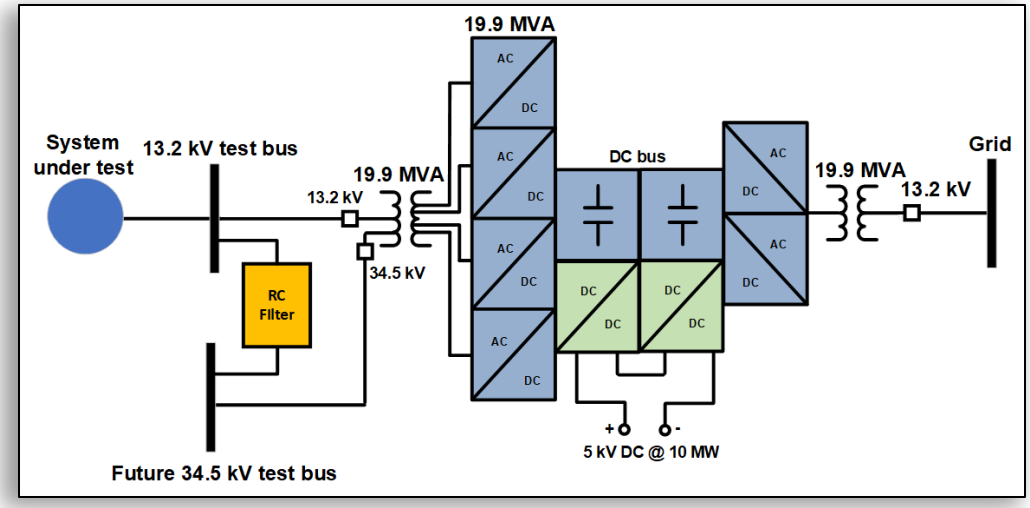
Grid Simulator #2: 19.9 MVA Continuous Power Rating

Power rating
- Continuous AC rating - 19.9 MVA at 13.2kV and 34.5 KV
- Overcurrent capability (x5.7 for 3 sec, x7.3 for 0.5 sec)
- 4-wire 13.2 kV or 35.4 kV taps
- Continuous operational AC voltage range: 0 - 40 kVAC
- Continuous DC rating – 10 MW at 5 kVDC

Possible test articles
- Types 1, 2, 3 and 4 wind turbines
- PV inverters, energy storage systems
- Conventional generators
- Combinations of technologies / hybrid systems
- Responsive loads

Voltage control (no load THD <1%)
- Balanced and unbalanced voltage fault conditions (ZVRT, LVRT and 140% HVRT) – independent voltage control for each phase on 13.2 kV and 34.5 kV terminals
- Response time – less than 1 millisecond (from full voltage to zero, or from zero back to full voltage)
- Programmable injection of positive, negative and zero sequence components
- Long-term symmetrical voltage variations (+/- 10%) and voltage magnitude modulations (0-10 Hz) – SSR conditions
- Programmable impedance (strong and weak grids, wide SCR range corresponding to a POI with up to 250 MVA of short circuit apparent power)
- Injection of controlled voltage distortions
- Wide-spectrum (0-2kHz) impedance characterization of inverter-coupled generation and loads
- All-quadrant reactive power capability characterization of any system

Frequency control
- Fast output frequency control (3 Hz/sec) within 45-65 Hz range
- 50/60 Hz operation
- Can simulate frequency conditions for any type of power system
- PHIL capable (can be coupled with RTDS)
- Coupled with PMU-based wide-area stability controls validation platform



100 µS response time

New features
- 5 kV MVDC grid simulator (PHIL capable)
- Voltage or current source operation
- Seamless transition between voltage and current source modes
- Emulation of full set of resiliency services:
  - Black start
  - Power system restoration schemes
  - Microgrids
- Flexible configurations are possible when combined with CGI#1:
  - Two independent experiments
  - Parallel operation
  - Back-to-back operation
  - Emulation of isolated, partially or fully grid-connected microgrids

Medium Voltage Impedance Network (MVIN)

MVIN – Shahil Shah / NLR

- Real emulation of weak grid conditions down to short-circuit ratio (SCR) of 1 for up to 7 MVA test articles
- Real emulation of series compensation, up to 50%

Grid Integration Testbed Control and Monitoring

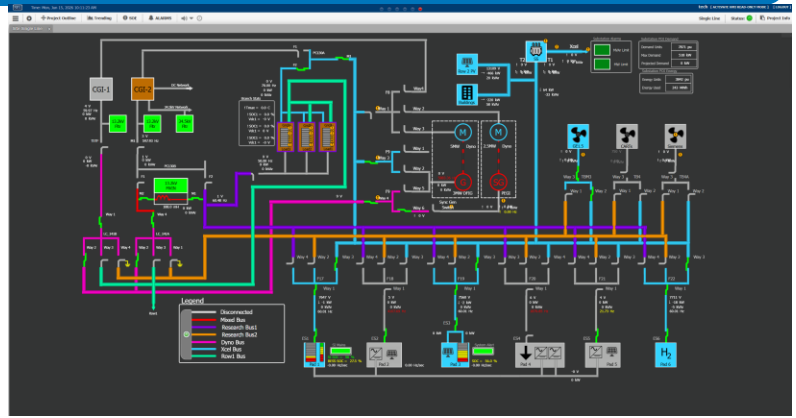
Control Center Facility (completed 2025) - Control room and real-time compute hardware (RTDS, Typhon, Opal, CGI Digital Twin)

SCADA – SEL RTAC real-time view of testbed configuration, state. Aggregates data from all assets, streams to continuous time series database

Time Series Data Base and Visualization – InfluxDB/Grafana

Automation – MATLAB based test scripting to synchronize CGI, test article, data collection, post processing and reporting

Medium Voltage Data Acquisition System (MVDAS)



SEL RTAC real time site status – Robb Wallen / NLR

Control Center Facility – Robb Wallen / NLR

Real-time compute hardware – Robb Wallen / NLR

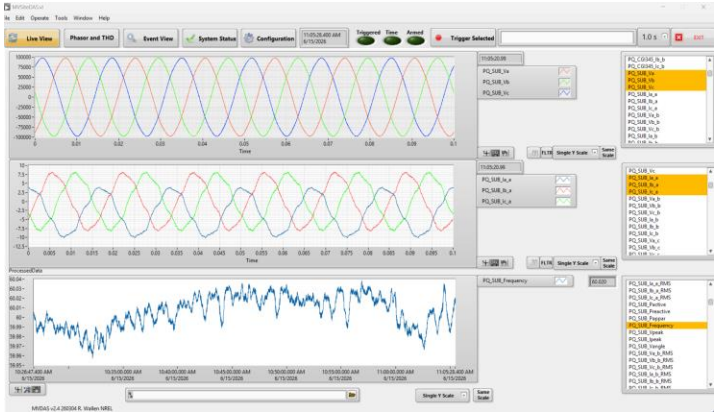
Control Room - Taylor Mankle / NLR

Medium Voltage Data Acquisition System (MVDAS)

- **Distributed** network of synchronized 24-bit, 50kHz, voltage and current measurement systems
- Central trigger, local data storage, automated data download and post processing
- Global oscilloscope client application
- **Continuous** stream of processed data to InfluxDB/Grafana
- Inhouse system design and built by NLR

MVDAS Measurement node – Robb Wallen / NLR

Resistive voltage divider and LEM sensor installation – Robb Wallen / NLR

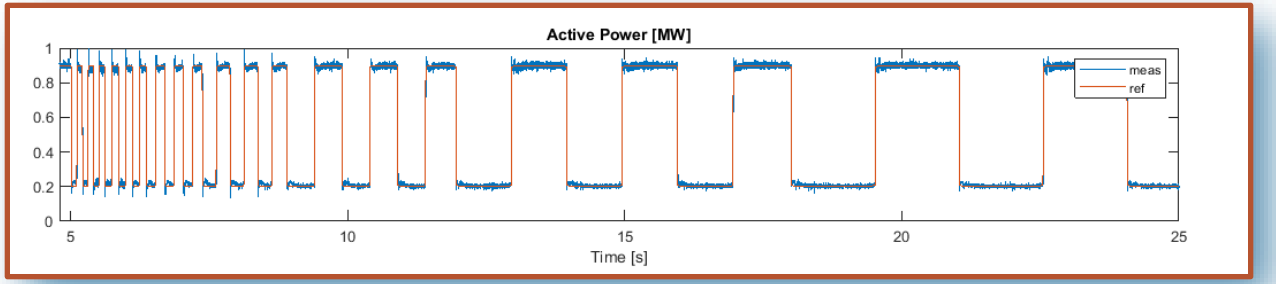


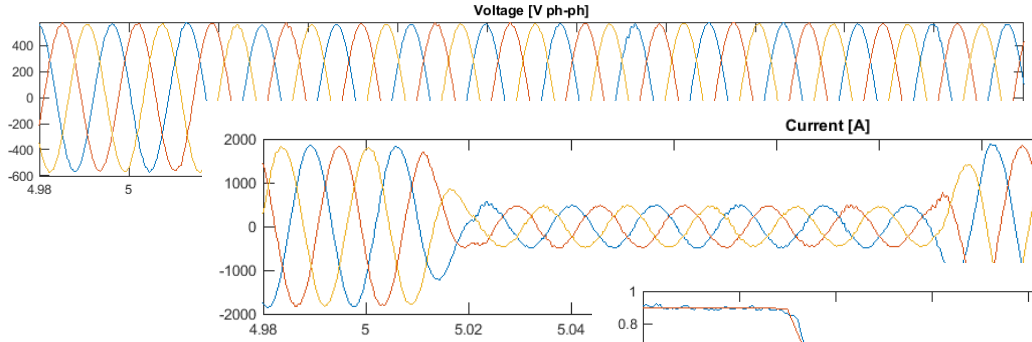
MVDAS Client application – Robb Wallen / NLR

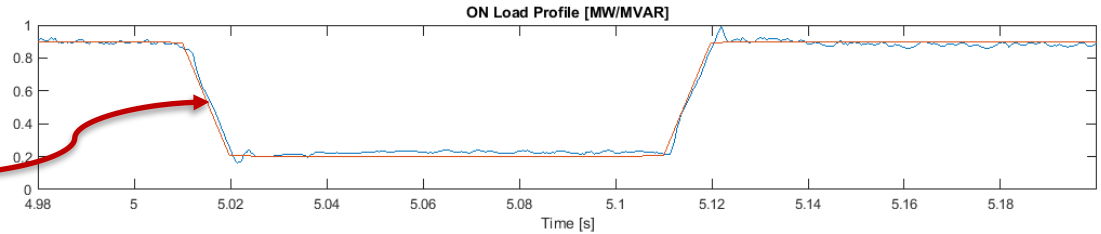
Grafana visualization – Robb Wallen / NLR

Testing Examples

Load-Side Testing: AI Load Profile Emulation





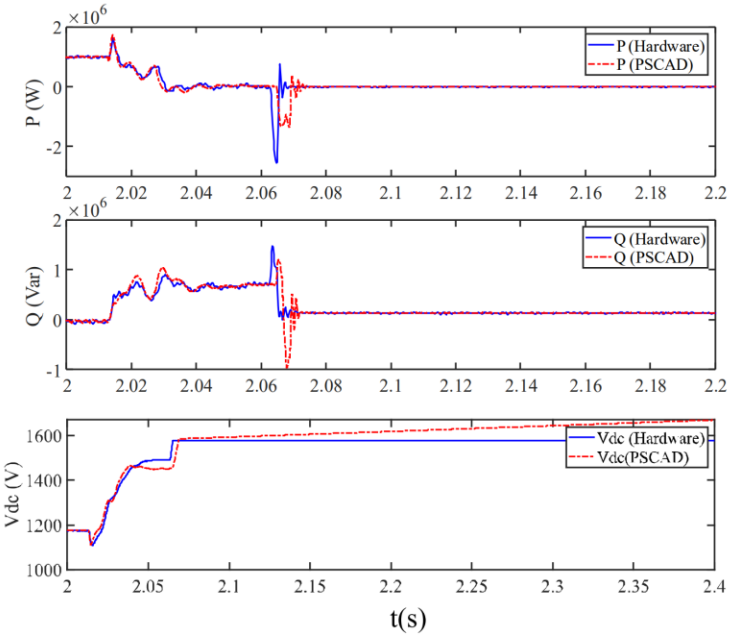


Response of a 2.2 MVA Inverter During AI Load Profile Emulation

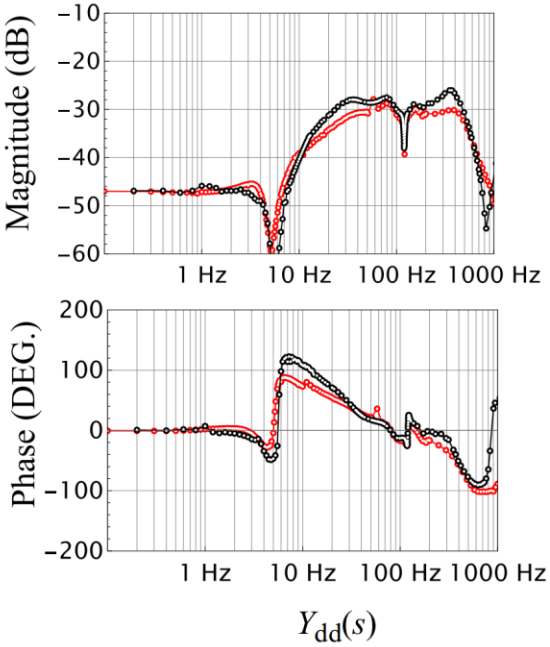
0.8 p.u in 10 ms

Grid-Side Testing and EMT Model Validation

- Voltage Dip Test
  - (60% voltage dip of 50 ms)



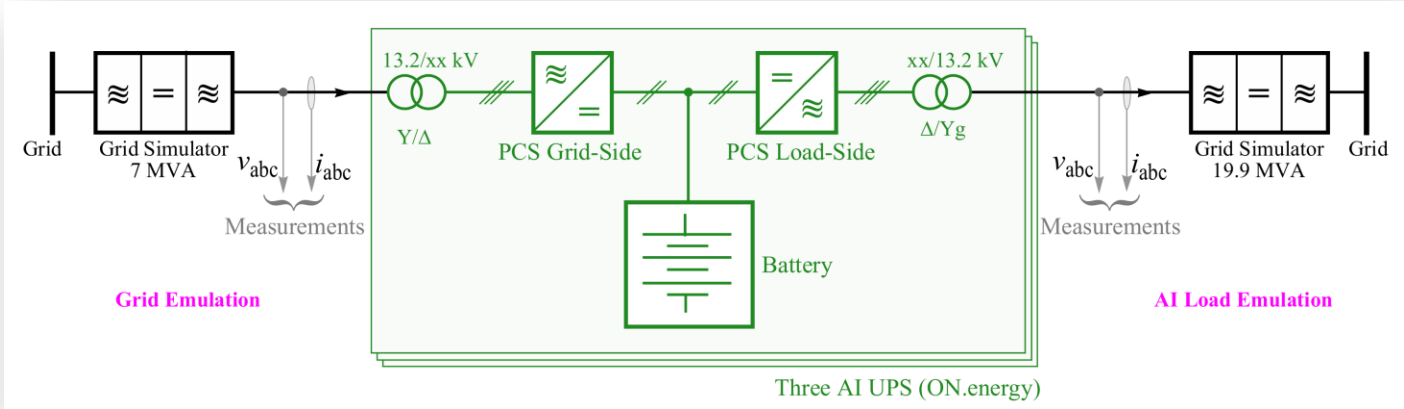
- Frequency Scan



Red: PSCAD Model
Black: Hardware Measurements

At Scale Testing of ON.energy's AI UPS

Derisking New Technologies for AI Factories



- **Tests**
  - AI load profile
  - AI load crash
  - Voltage ride-through
  - Weak grid
  - EMT model validation
- **Goals**
  - De-risk and debug of AI UPS in a controlled environment
  - Demonstrate grid-side and load-side performance

AI UPS from ON.energy

Nov. 2025

Dec. 2025

April 2026

Testing of Grid-Side and Load-Side Performance of AI UPS

Load-side Disturbances

1. Power drawn from the grid does not see AI load fluctuations
2. Voltage level for the AI load maintained within limits
3. Power demand from grid slowly ramps down during AI load crash

Grid-side Disturbances

4. LVRT/HVRT events on grid-side voltage per ERCOT NOGR profile
5. LVRT event – 100 %, 100 ms

Summary

- Technologies for power delivery in data centers are evolving rapidly in response to changing performance requirements from AI loads and power grids.
  - BESS, UPS, E-STATCOM, …
- At scale testing can de-risk these technologies and improve confidence in their EMT models used for grid planning and operation.
- Standardized performance requirements and test protocols are required to improve supply chain and compliance with grid interconnection requirements of data center power system equipment.

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