Why Hardware-in-the-Loop Testing is the Secret to Field-Ready SCADA.

- Chathura Patabandi
- Nayak Corporation

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RTDS Technologies
AMETEK

About Nayak Corporation

- Established in 1999, located in Hamilton, New Jersey, USA
- Former developers of PSCAD power system simulator
- Independent representatives for

PSCAD emt simulator from Manitoba Hydro International

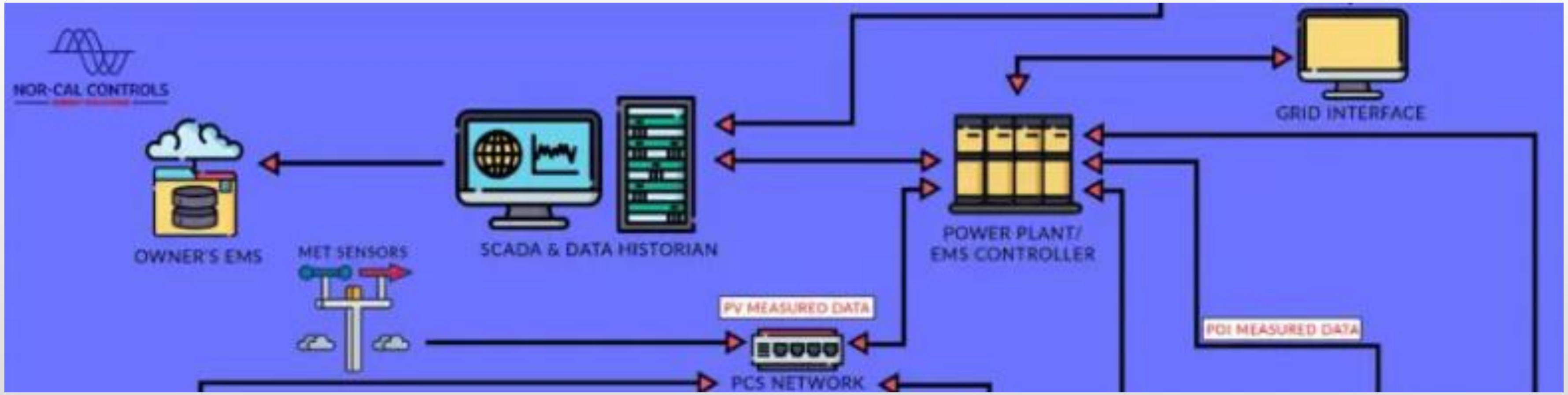
RTDS real time digital simulator from RTDS Technologies

Linear Power Amplifiers from Spitzenberger and Spies

- Provides sales, support and training
- PSCAD and RTDS System study consulting services

Nor-Cal Controls

- Located in Folsom, CA
- Controls systems integrator
- Utility-scale Solar PV & Energy Storage
- Purpose-built SCADA & EMS
- Background in traditional controls

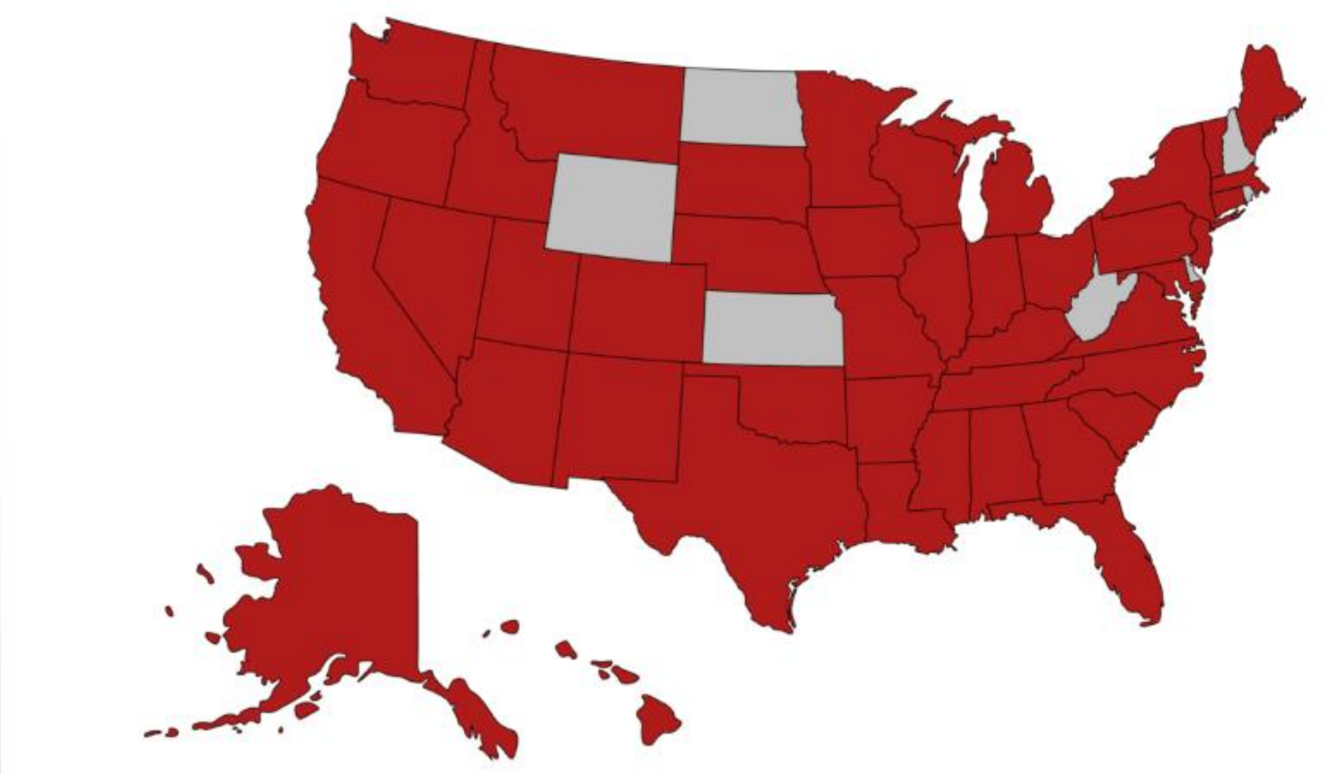


Nor-Cal Controls

PROVEN AT SCALE

NATIONWIDE EXPERIENCE

- Projects in **43 states**
- Familiar with all major ISOs & utilities—CAISO, ERCOT, PJM, SPP, MISO, NYISO, ISO-NE



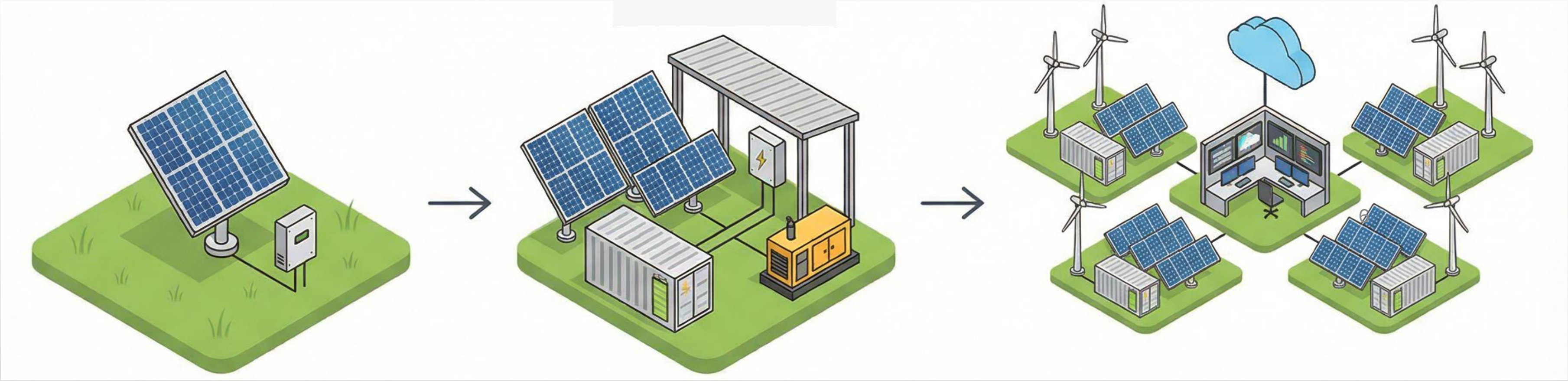
681	38.20 GWac	13.88 GWh
Renewable Energy Projects	Solar Projects	Storage Projects

Hardware-In-The Loop Testing?

- A validation technique where real hardware, such as controllers (PPC), RTACs, and SCADA Rack components, is tested against a simulated environment that mimics real-world plant behavior.
- Advantage: Instead of waiting for a fully constructed site, we can replicate plant conditions in a controlled lab setting.

Why HIL in Renewables?

- The grid is changing rapidly
- Assets are more complex
- SCADA & controls now drive performance



Why HIL in Renewables?

- Early Detection of Integration issues:
  - PV SCADA systems often integrate multiple subsystems—Power Plant Controllers (PPC), inverters, and BESS Controllers.
  - HIL testing enables communication mismatches, protocol issues, and data inconsistencies early in the development phase, long before commissioning.
- Validation of Control Logic
  - Control strategies such as active/reactive power control, ramp rate limiting, and curtailment must function precisely to meet grid codes.
  - HIL allows these algorithms to be tested dynamically under varying simulated grid conditions (e.g., voltage fluctuations, frequency deviations), ensuring robustness and compliance.

Why HIL in Renewables?

- Reduced Commissioning Risk
  - Commissioning is often time-constrained and costly.
  - Any delays due to unexpected SCADA issues can have a significant financial impact.
  - By validating SCADA behavior in advance through HIL, teams can drastically reduce on-site troubleshooting and accelerate commissioning timelines
- Testing Edge Cases and Fault Conditions
  - Certain scenarios—such as inverter trips, hardware failure, communication loss, and redundancy check —are difficult or risky to test in a live plant.
  - HIL environments make it possible to safely simulate these edge cases and verify system responses without impacting actual operations.

Why HIL in Renewables?

- Improved System Reliability
  - A thoroughly tested SCADA system translates to fewer operational issues post-commissioning.
  - HIL testing helps ensure stable performance, accurate data acquisition, and reliable control actions, ultimately improving plant uptime and performance.
- Facilitating Standardization and Reusability
  - For organizations deploying multiple PV projects, HIL testing provides a framework for validating standardized SCADA templates and control logic.
  - This improves consistency across projects and reduces engineering effort over time.

HIL Testing of Hybrid Plants?

- Most renewable plants are designed with more than one resource
  - PV+BESS
  - Wind+BESS
  - etc
- With multiple resources, the complexity of control and coordination rises significantly.
- These resources may have more than one controller—typically a PV Power Plant Controller (PV PPC) and a BESS Power Plant Controller (BESS PPC)
- must operate in a tightly coordinated manner to meet grid requirements and optimize plant performance.

Why This Coordination Matters?

Hybrid sites are expected to behave as a single grid-facing resource. This means:

- Coordinated active/reactive power dispatch (capped limit at POI)
- Seamless transitions between PV generation and battery charge/discharge
- Compliance with grid commands such as AGC (Automatic Generation Control) or ramp rate limits
- Maintaining a unified Point of Interconnection (POI) response

Any mismatch between controllers can lead to instability, non-compliance, or inefficient operation.

Role of HIL Testing in Hybrid Control Validation

- HIL testing allows both controllers to be tested together under realistic, dynamic conditions.
- HIL enables validation of communication and coordination logic between PV PPC and BESS PPC.
- This includes verifying how setpoints are shared, prioritized, and executed across both systems.

Testing under Different Operating Scenarios

Different operating scenarios can be simulated, such as:

- PV-only generation during the day
- Battery charging using excess PV generation
- Battery discharging during low irradiance or grid demand
- Combined PV + BESS dispatch to meet POI limits
- PV and BESS coordination for PFR (Primary Frequency Response)
- PV and BESS coordination for Voltage fluctuations

Critical transitions—such as switching from charging to discharging, or sudden PV drops due to cloud cover—can be simulated to verify smooth and stable system behavior.

HIL makes it possible to test failure modes like Communication loss between PPCs and Conflicting Control Commands safely. This ensures fallback strategies and fail-safe mechanisms are properly implemented.

Master Plant Controller?

As PV and hybrid plants scale up, a common control architecture involves a Master Plant Controller (MPC) supervising multiple local Power Plant Controllers (PPCs).

This hierarchical approach is often used in large or geographically distributed sites, where multiple resources (PV/BESS) have their own PPCs, while the MPC manages plant-level objectives at the Point of Interconnection (POI).

HIL Testing of Master Controller

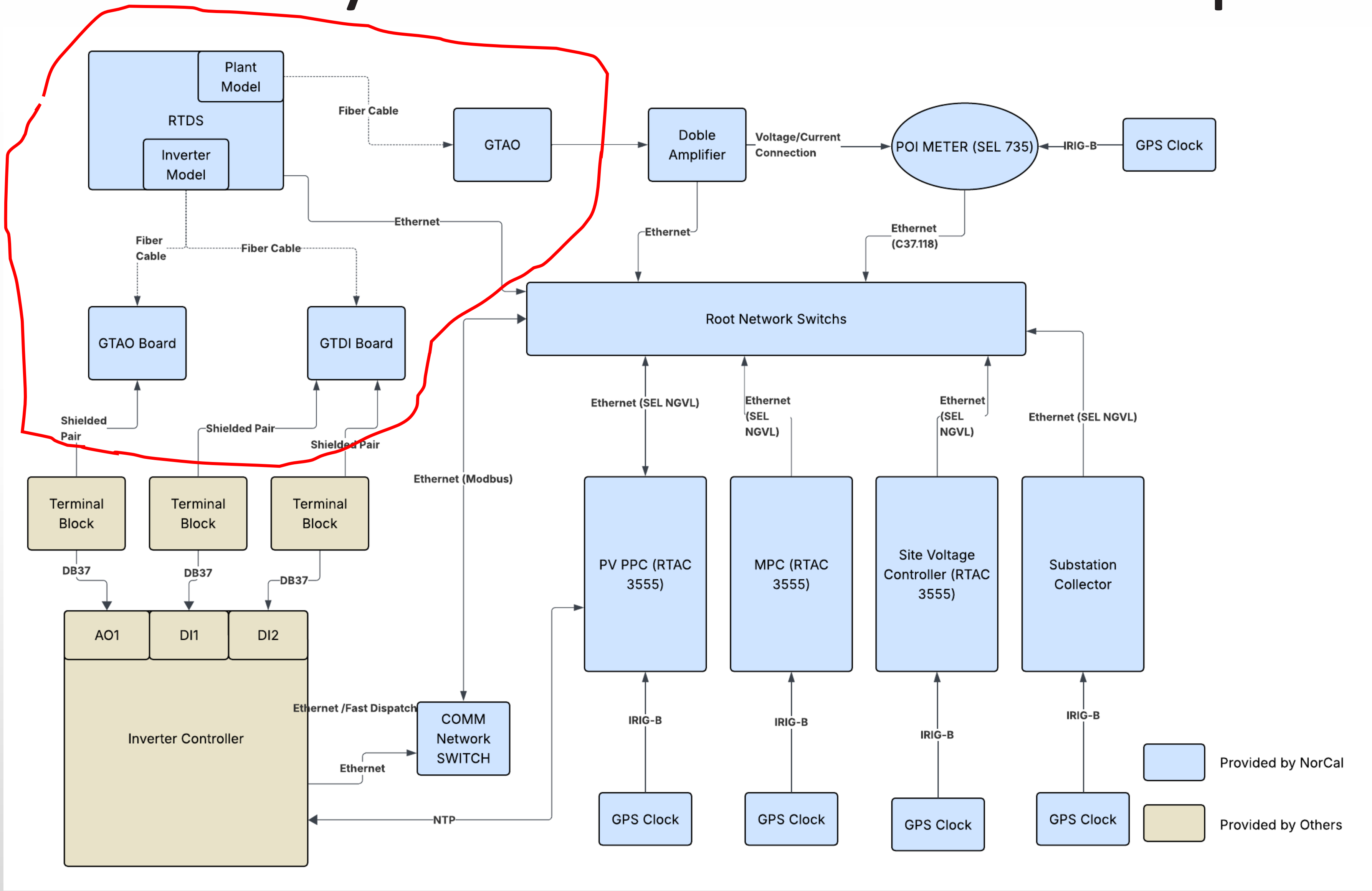
- While this architecture improves scalability and modularity, it also introduces another layer of coordination complexity, making HIL testing even more critical.
- HIL enables full system testing from MPC down to individual PPCs by simulating plant behavior and verifying that plant-level commands are correctly distributed and executed across all local controllers.
- The MPC typically distributes setpoints among multiple PPCs based on availability, capacity, or predefined priorities.
- HIL testing helps validate Real and Reactive power distribution among resources, and dynamic redistribution when one of the resources reaches its limit or becomes unavailable.
- HIL makes it possible to simulate loss of one or more PPCs, partial plant outages, MPC fallback or local PPC autonomous control modes.
- This ensures the system remains stable and compliant even under abnormal conditions.

Key Components in a Nor-Cal SCADA HIL Setup

A typical HIL setup for SCADA systems may include:

- Real SCADA servers and Networking Equipment
- Power Plant Controller (PPC) hardware
- Simulated inverter model (RSCAD) or Hardware Inverter Controller
- Grid Simulation and Plant Model (RSCAD)
- POI Meter
- Communication networks (Modbus, DNP3, IEC protocols)

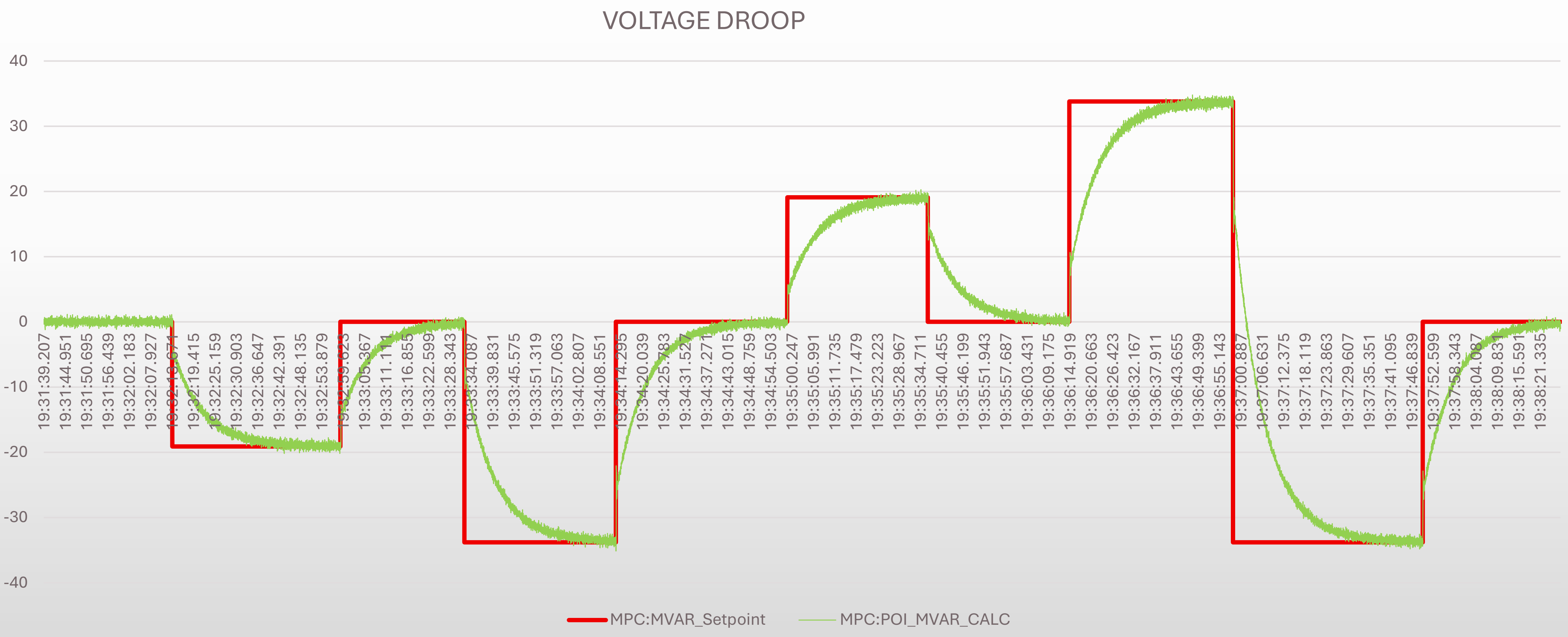
Sample Case Study - Overview of HIL Setup



Sample Case Study - Testing

- ***Real Power Modes***
  - **Frequency Droop Mode**
    - The frequency droop will be enabled for this test.
    - The tests will be performed with headroom
    - Fref is forced into the MPC and will vary between 59 – 61 Hz in multiple steps
- **Reactive Power Modes**
  - **Voltage Control Mode**
    - The PPC will be set to voltage control mode.
    - The voltage reference will be changed in multiple steps by adjusting the Vref setpoints in the Site Voltage Controller.

Sample Case Study – Simulation Results



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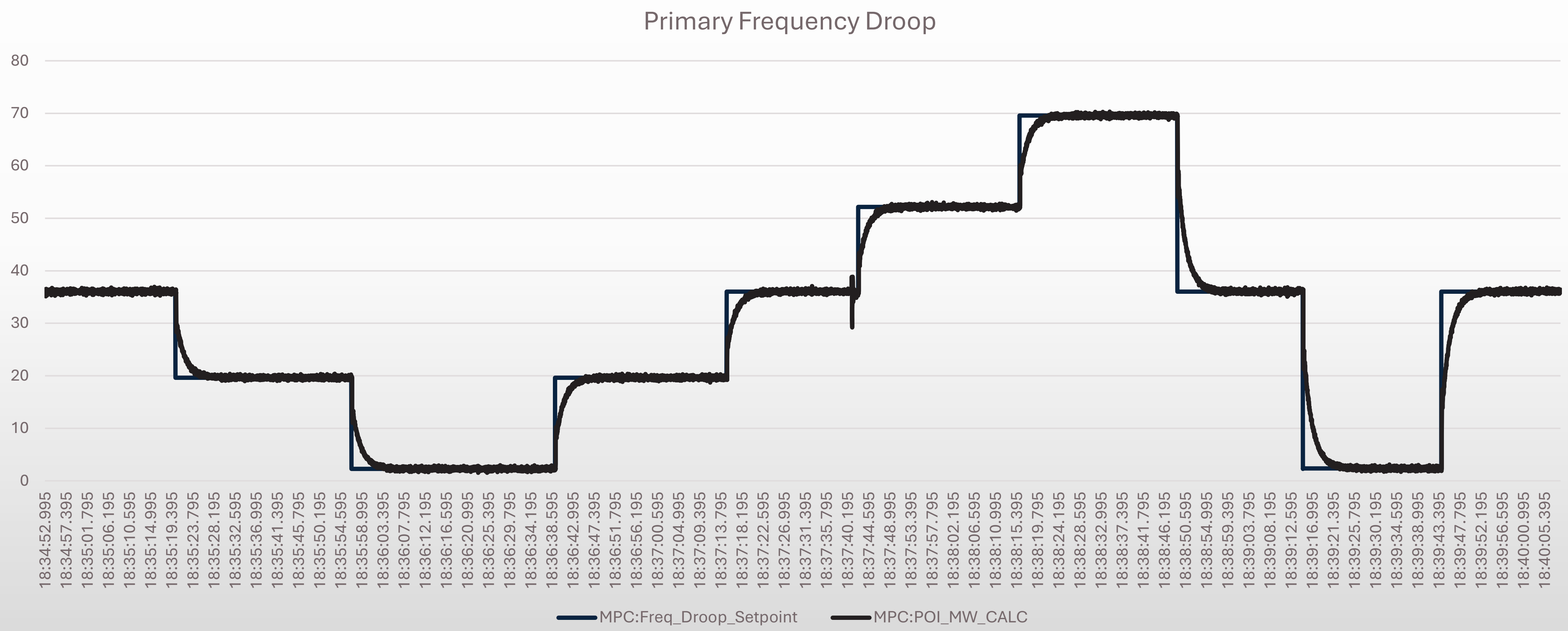

Conclusion

In today's utility-scale Renewable landscape, SCADA systems are too critical to rely solely on field testing.

Hardware-in-the-Loop testing bridges the gap between design and real-world deployment, enabling SCADA providers to validate performance, mitigate risks, and ensure smooth project execution.

HIL testing provides a powerful platform to ensure that PV PPC and BESS PPC operate as a unified, reliable, and grid-compliant system for Hybrid Plants—well before the plant goes live.

Investing in HIL testing is not just about improving quality; it's about delivering reliable, compliant, and efficient solar plants in an increasingly demanding energy market.

HIL testing plays a vital role in verifying, measuring, and optimizing system response, ensuring that PV and hybrid plants can meet these demands reliably and confidently.