ENERGISE Program Kickoff

DOE Award #: 32931

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Voltage Regulation and Protection Assurance using DER Advanced Grid Functions

Jay Johnson, Sandia National Laboratories

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Project Team

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Organization	Names	Main Responsibilities
Sandia National Laboratories	Jay Johnson (PI) Cliff Hansen Matt Reno Jimmy Quiroz Rachid Darbali	Project management, forecasting, circuit modeling, HIL validation, optimization, cybersecurity
SunSpec Alliance	Tom Tansy Bob Fox	Standards, interoperability, communications, cybersecurity
Georgia Tech	Sakis Meliopoulos George Cokkinides Boqi Xie Chiyang Zhong	State estimation, protection, voltage control/DER setpoint optimization
EPRI	Brian Seal Jithendar Anandan	PV simulator for HIL experiments, distribution modeling
SunPower	Pat Chapman Miles Bintz Phil Rothblum	Communications, customer engagement
BPL Global	Mark Rupnik Terry Rohrer Chad Showalter	Chief software architect, programming management, DERMS deployment
National Grid	Justin Woodard	Utility interests, feeder data, DERMS deployment
PNM	Jon Hawkins	Utility interests, feeder data, DERMS deployment

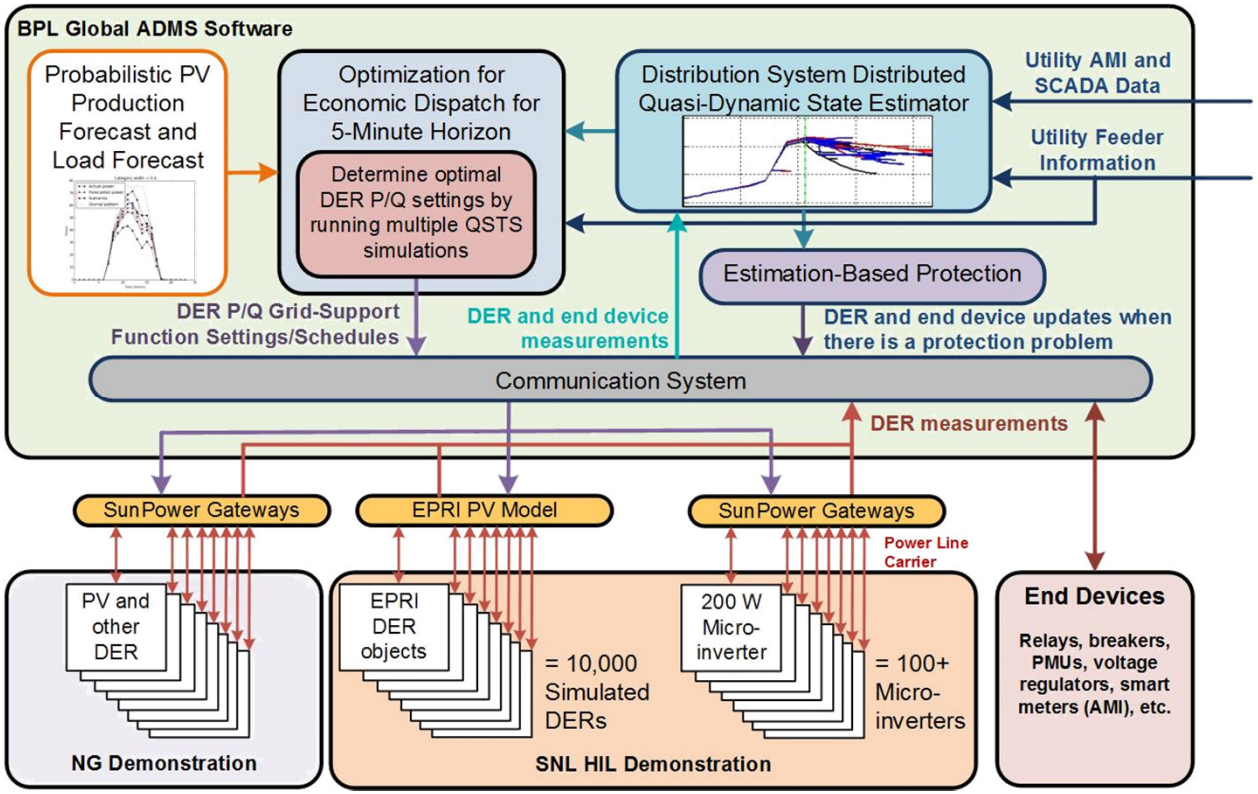
Project Goals

- Create open-source software platform that addresses the spectrum of distribution circuit and DER management including: state estimation, voltage regulation, protection, economic optimization, communications, and cybersecurity.

- Safely allow PV penetrations of 50% or greater by providing real-time visibility into distribution circuits and optimizing the active and reactive (P/Q) DER settings to meet voltage regulation, protection, and economic objectives in the presence of solar variability.

System Architecture

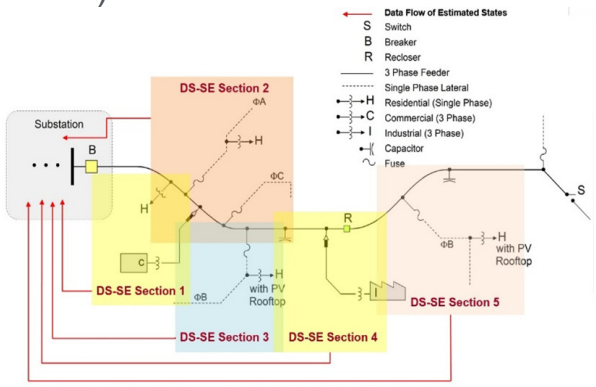
- Programmable Distribution Resource Open Management Optimization System (ProDROMOS)
  - Prodromos is Greek for "forerunner" and the prodromoi were a light cavalry army unit in ancient Greece used for scouting missions.



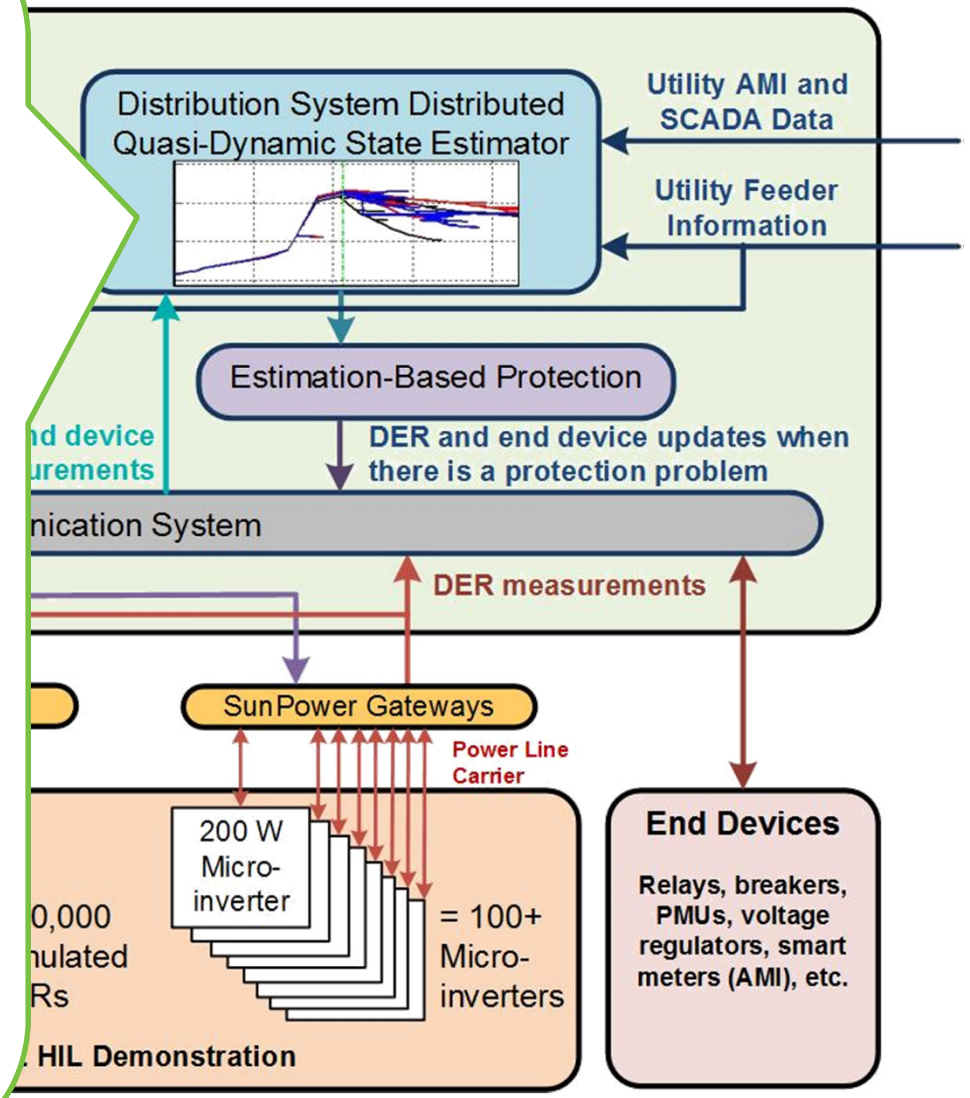
System Architecture

Distribution System Distributed Quasi-Dynamic State Estimator (DS-DQSE)

- **Ingests feeder telemetry** from DER and out-of-band sources (customer data)
- Generates the voltage profile and **power flow estimation** with scalable solution
- Operates on partitioned distribution system with solutions at up to **60 times/second**
- Deployed on U.S. Virgin Islands (WAPA)



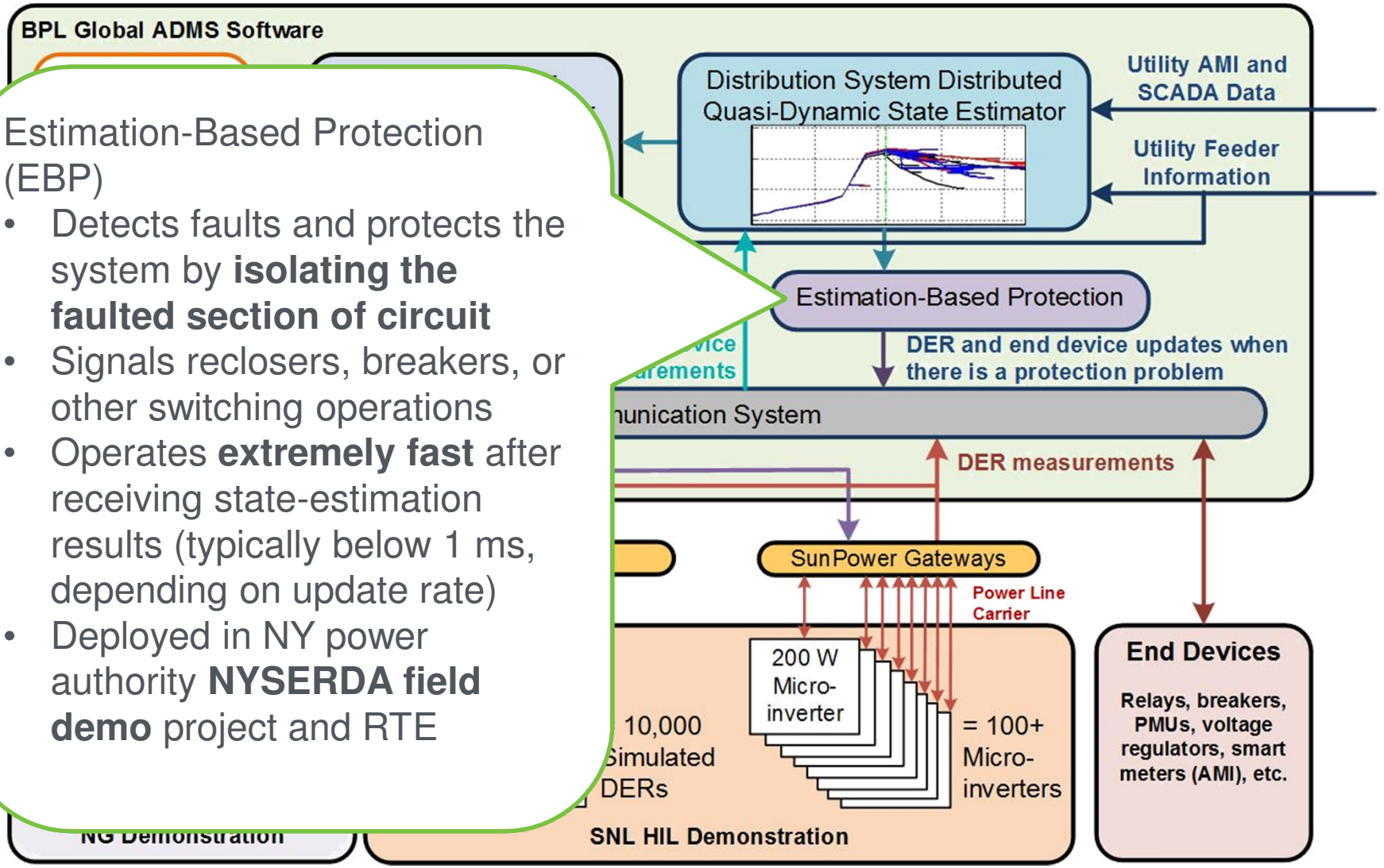
See: A.P. Meliopoulos, G. Cokkinides, B. Xie, C. Zhong, J. Johnson, "Full State Feedback Control for Virtual Power Plants," Sandia Technical Report, SAND2017-10178, September 2017.



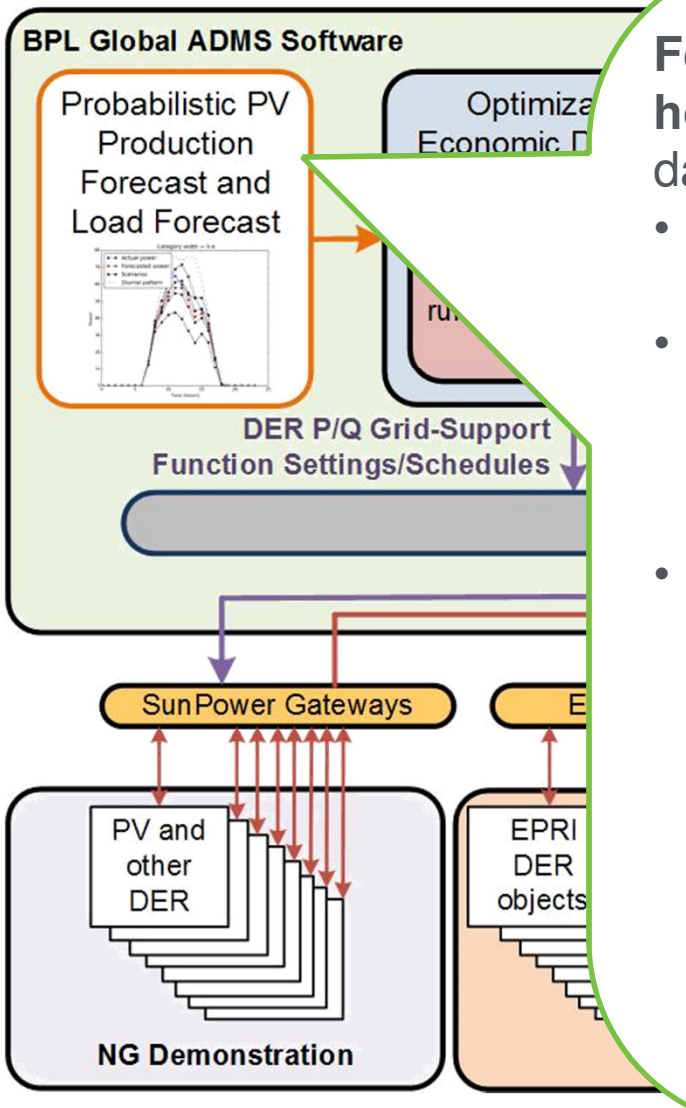
System Architecture

Estimation-Based Protection (EBP)

- Detects faults and protects the system by **isolating the faulted section of circuit**
- Signals reclosers, breakers, or other switching operations
- Operates **extremely fast** after receiving state-estimation results (typically below 1 ms, depending on update rate)
- Deployed in NY power authority **NYSERDA field demo** project and RTE

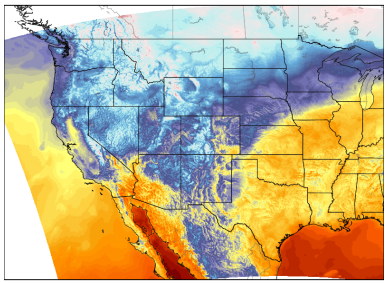


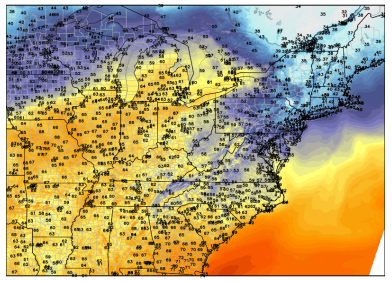
System Architecture



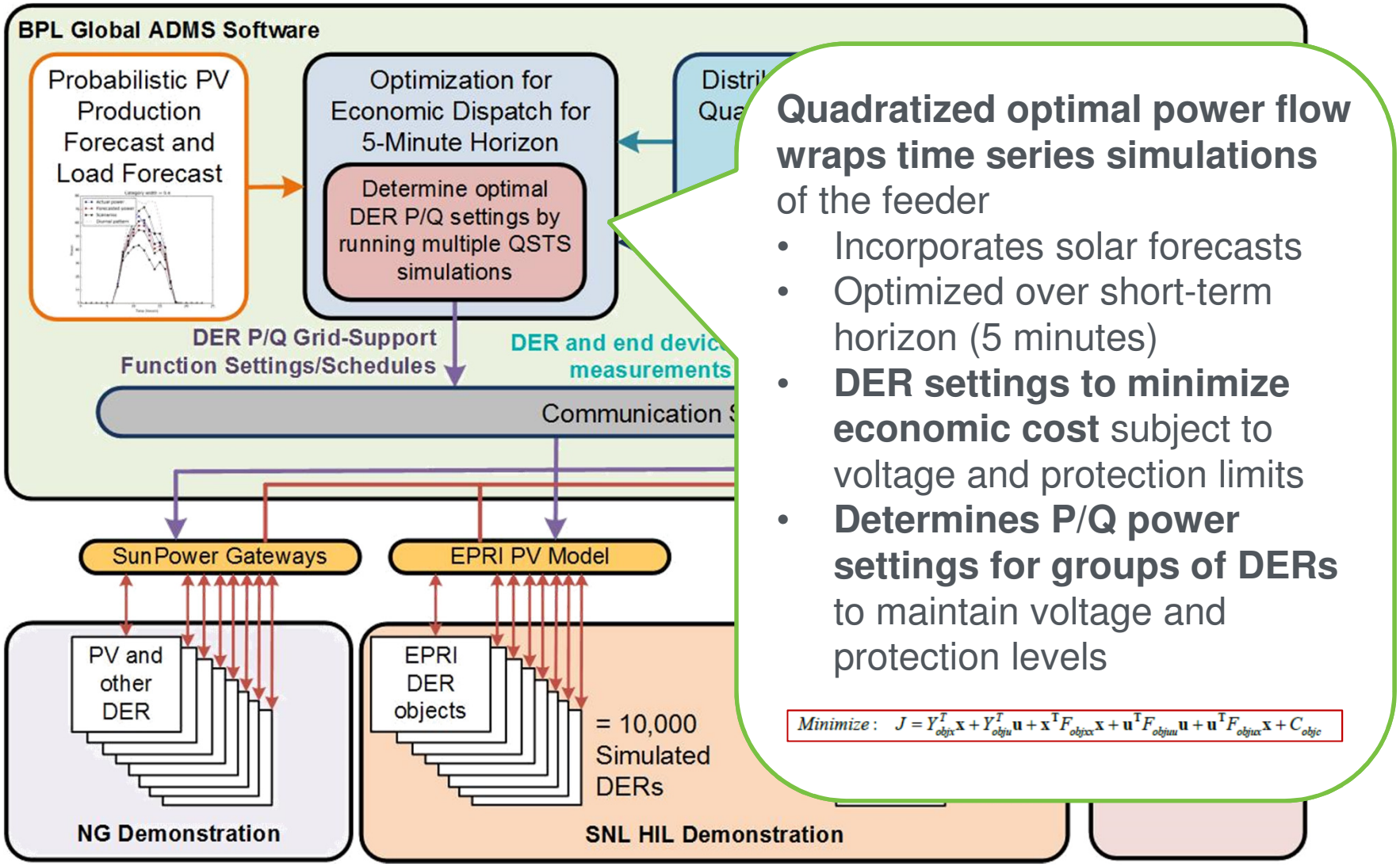
Forecasts at 1-min time-steps with a 2-hour horizon from system telemetry and NOAA data

- **Forecast uncertainty characterized by historical record**
- Autoregressive integrated moving-average (ARIMA) model used to generate **short-term irradiance forecasts** (as opposed to persistence models)
- Converts NOAA **irradiance to PV power** using National Centers for Environmental Prediction (NCEP) High-Resolution Rapid Refresh (HRRR) and Sandia Array Performance Model





System Architecture

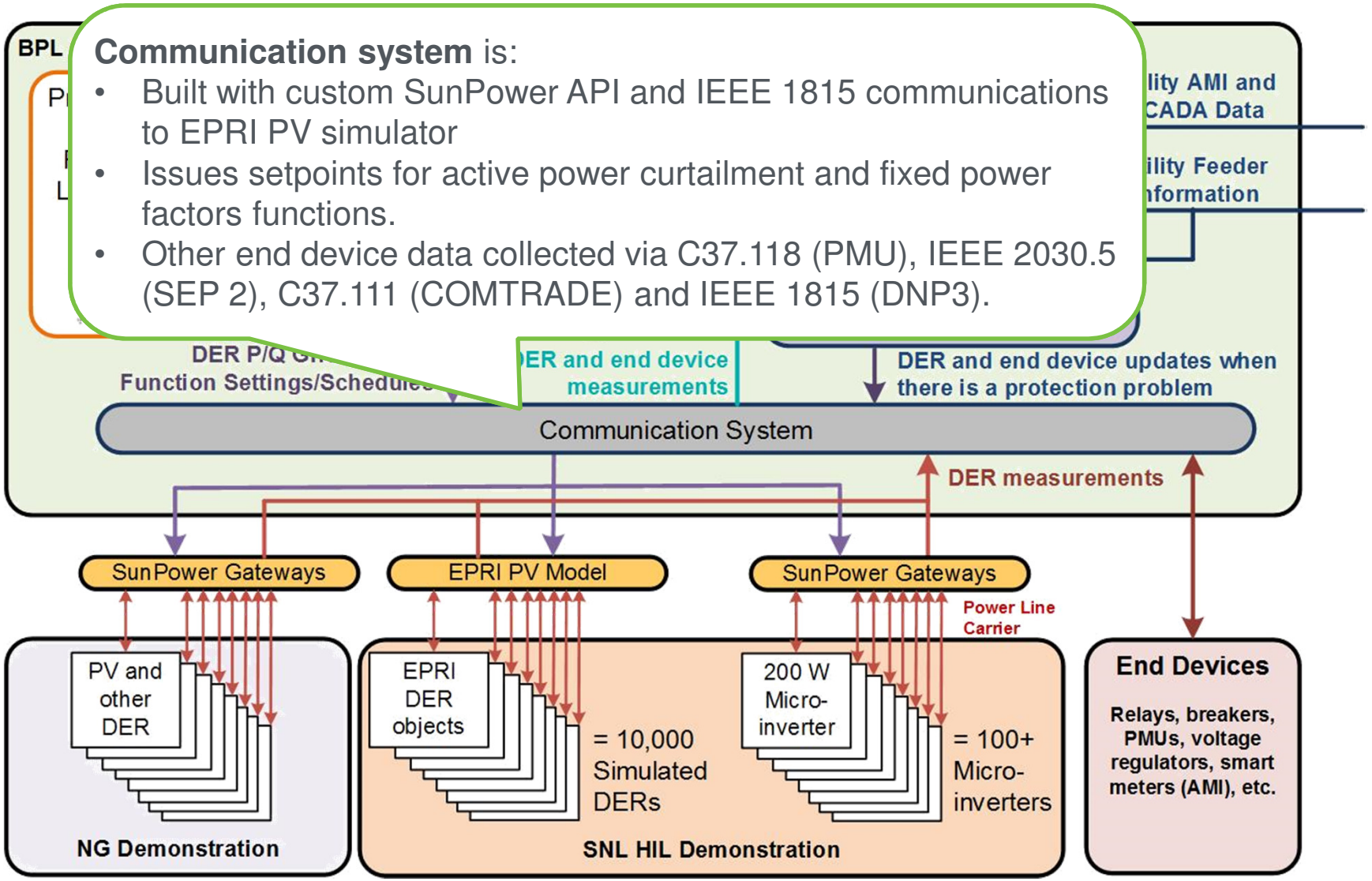


Quadratized optimal power flow wraps time series simulations of the feeder

- Incorporates solar forecasts
- Optimized over short-term horizon (5 minutes)
- **DER settings to minimize economic cost** subject to voltage and protection limits
- **Determines P/Q power settings for groups of DERs** to maintain voltage and protection levels

$$Minimize: \quad J = Y_{objx}^T \mathbf{x} + Y_{obju}^T \mathbf{u} + \mathbf{x}^T F_{objxx} \mathbf{x} + \mathbf{u}^T F_{objuu} \mathbf{u} + \mathbf{u}^T F_{objux} \mathbf{x} + C_{objc}$$

System Architecture



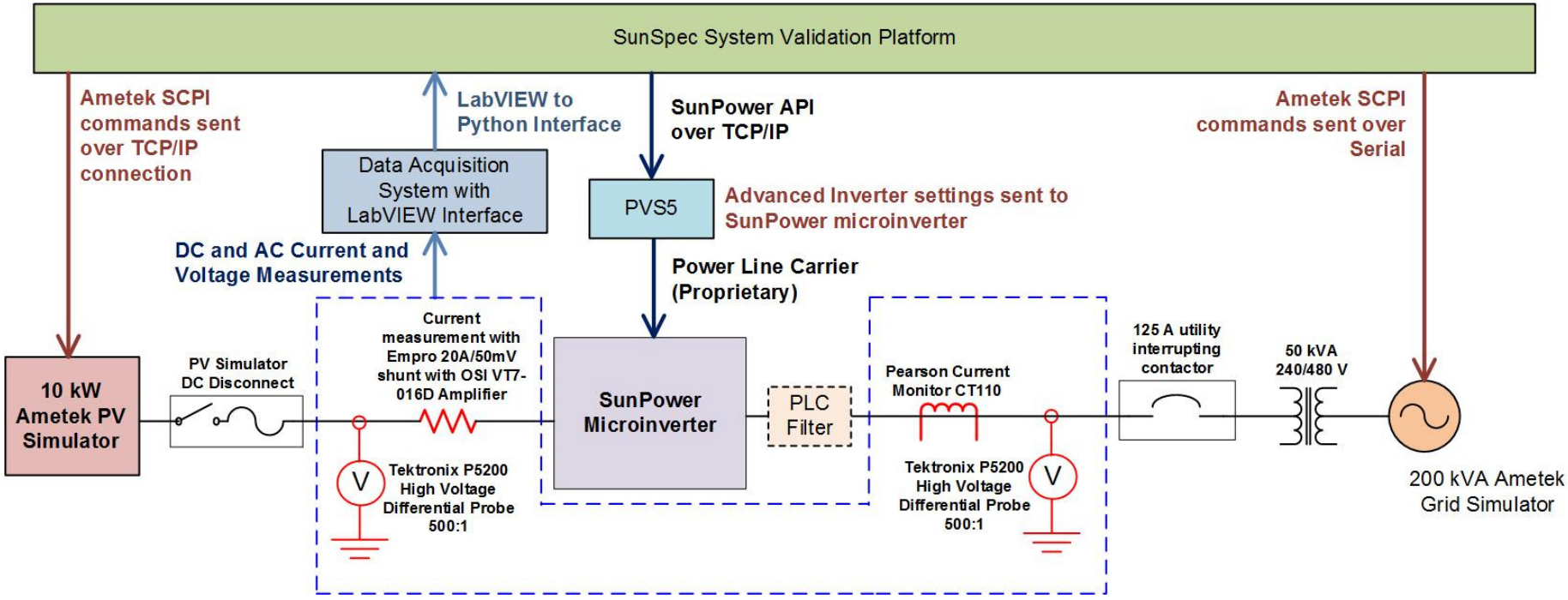
Communication system is:

- Built with custom SunPower API and IEEE 1815 communications to EPRI PV simulator
- Issues setpoints for active power curtailment and fixed power factors functions.
- Other end device data collected via C37.118 (PMU), IEEE 2030.5 (SEP 2), C37.111 (COMTRADE) and IEEE 1815 (DNP3).

Experimental Stages

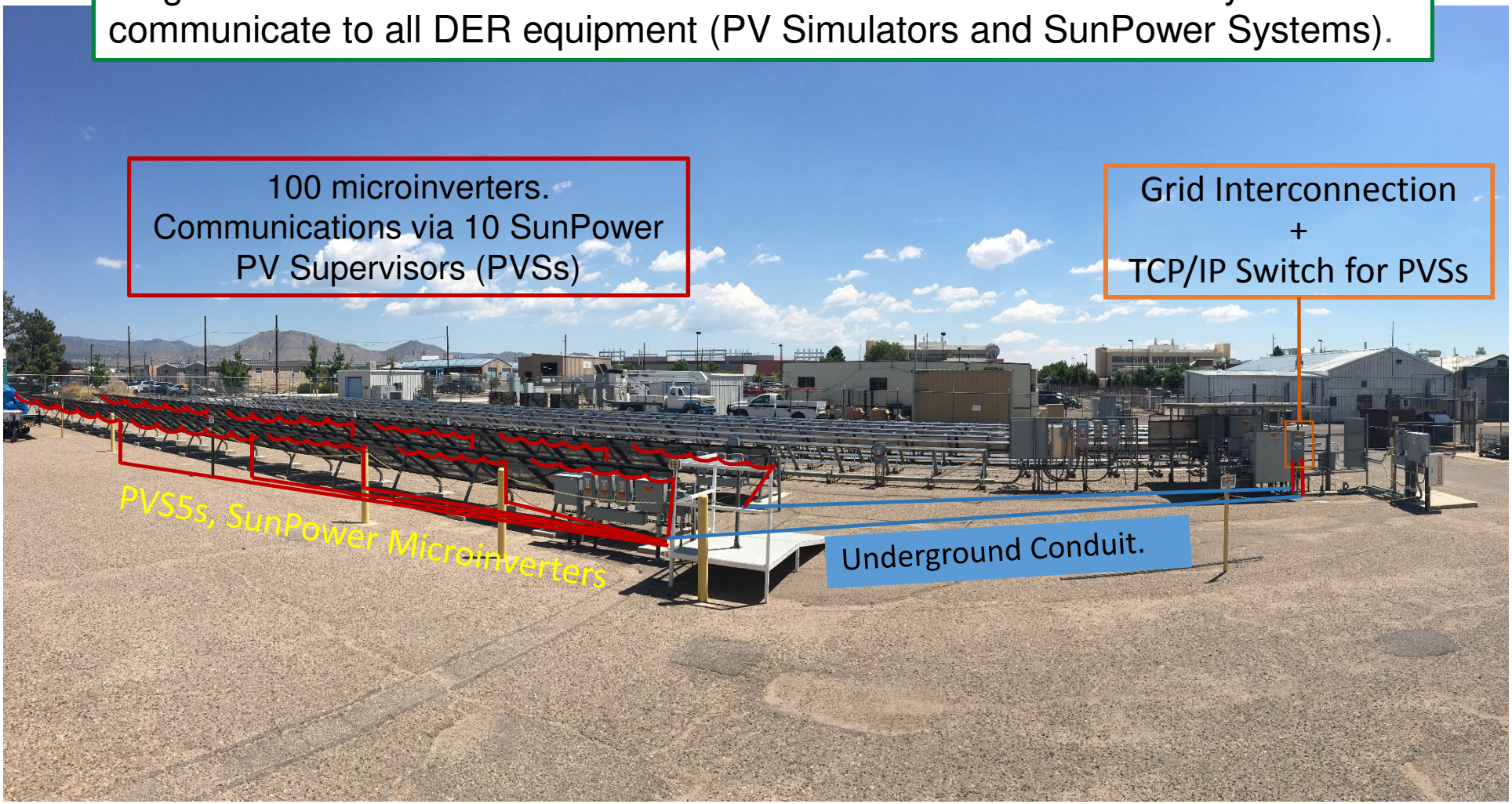
- The project is divided into **4 experimental stages** that move the ADMS components from the R&D environment to field demonstration.

Stage 1: Quantify/verify DER interoperability and P/Q characteristics.



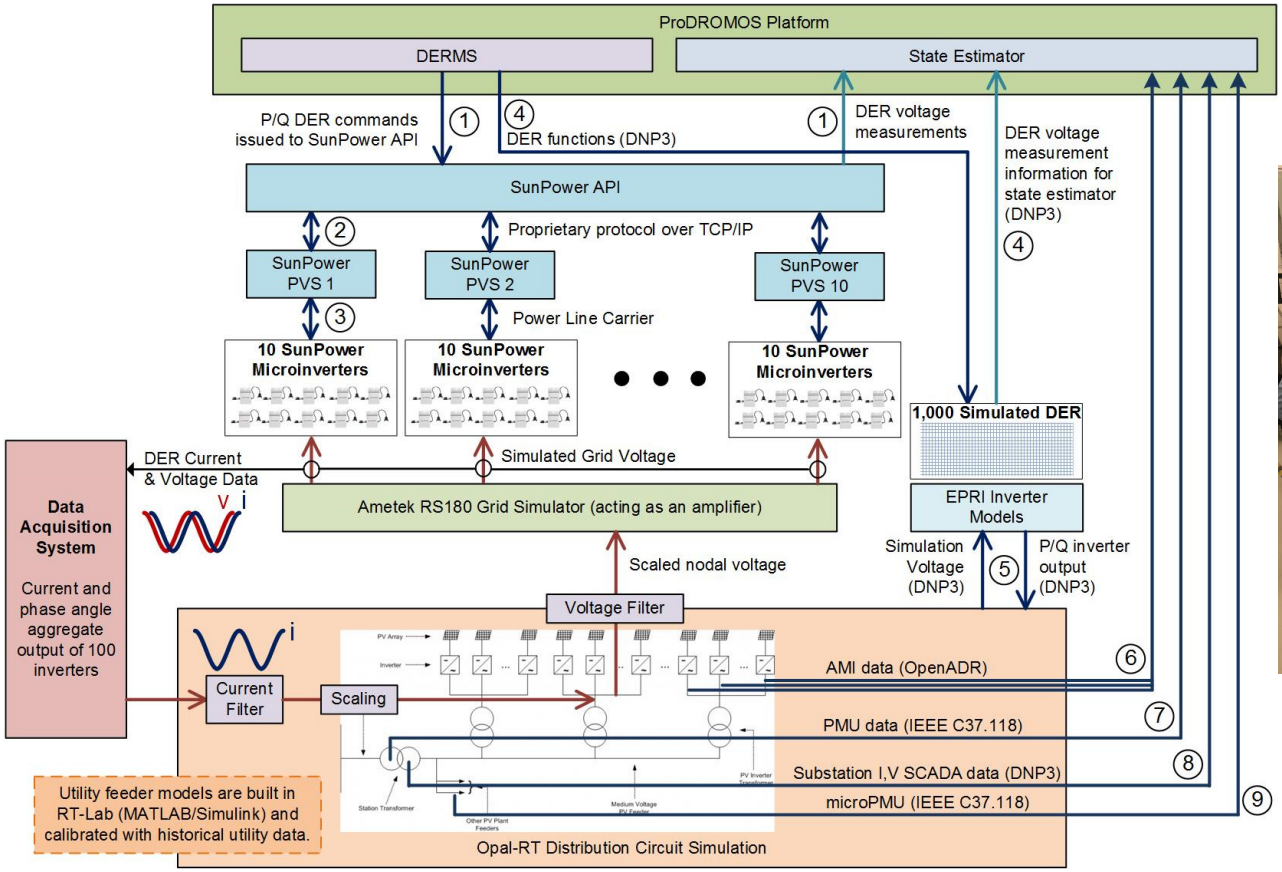
Experimental Stage #2

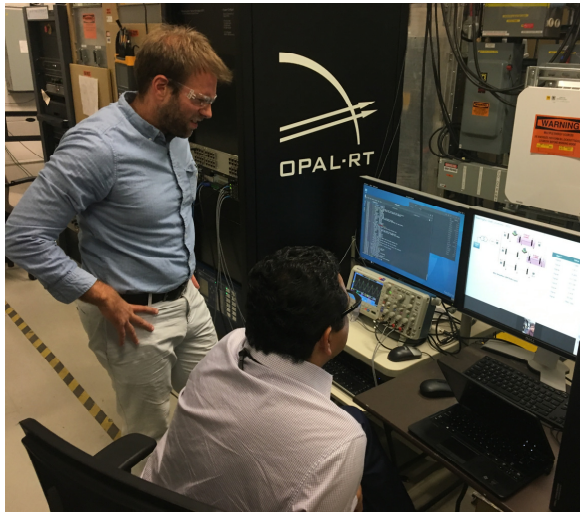
Large-scale communication verification. Demonstrate BPL Global system can communicate to all DER equipment (PV Simulators and SunPower Systems).



Experimental Stage #3

Distribution circuit power hardware-in-the-loop (HIL) simulations.





Opal-RT distribution circuit simulation at the Distributed Energy Technologies Laboratory (DETL) at Sandia National Laboratories.

Experimental Stage #4

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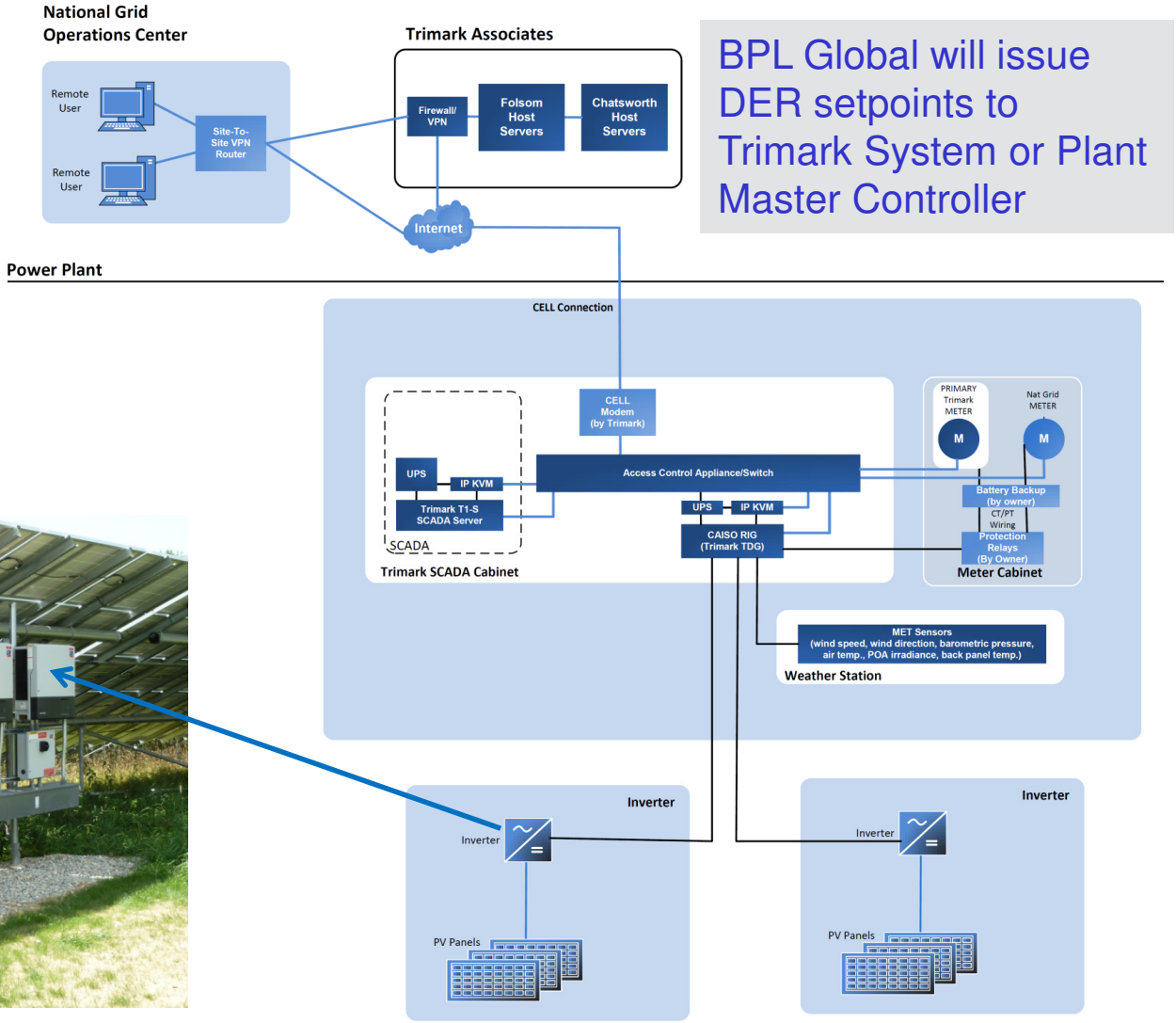
National Grid Field Demonstration

Considering two feeders based on PHIL experiments:

1. 684 kW controllable PV at Oxford Road Site, 1.9 MW legacy PV
2. 684 kW controllable PV at 24 Boutilier Road Site, 4.88 MW legacy PV



BPL Global will issue DER setpoints to Trimark System or Plant Master Controller

Major Innovations/Contributions

- ProDROMOS **leap-frogs current technologies** by **productizing innovative technologies** from Sandia and Georgia Tech
  - Moves revolutionary lower-TRL technologies to market quickly
    - DER economic dispatch to accomplish voltage regulation and distribution protection
    - Estimation-based protection
- **Open-sourcing technology allows all ADMS/DERMS manufacturers to benefit**
  - Creates standardized data flows, data architecture, and database exchange format/protocols
- Massive **cyber security component** of project
  - Establishes **cyber security working group** for DER vendors, utilities, and aggregators

Main Project Tasks/Subtasks

Year 1

- **Task 1: Identify utility feeders for simulations, install DER.**
- **Task 2: Open-source short-term solar forecasting tool.**
- **Task 3: Create state estimation tool.**
- **Task 4: Create Estimation-Based Protection system.**

Year 2

- **Task 1: Create optimization platform.**
- **Task 2: Create interoperability platform and improve cyber security posture.**
  - Cyber assessments of microinverter communications
  - Establish DER Cyber Security Working Group
- **Task 3: Conduct PHIL experiments.**
- **Task 4: Field demonstrations at National Grid.**

Project Milestones/Deliverables

- **Year 1 – Release source code for ProDROMOS components** with documentation
  - **Standardized open-source data architecture and database exchange format/protocols** published for:
    - Solar modelling tool, state estimation tool, estimation based protection tool, voltage regulation optimization algorithms and code: https://github.com/sunspec/prodromos
    - Research/reports/documentation: https://www.researchgate.net/project/Voltage-Regulation-and-Protection-Assurance-using-DER-Advanced-Grid-Functions
  - Establish **cybersecurity working group**
    - https://sunspec.org/sunspec-cybersecurity-workgroup/

- **Year 2 – Report on PHIL and field demonstrations**
  - Report **electrical behavior characteristics of DER** equipment, communication latencies, and cyber security assessment findings
  - **Publish PHIL results** for state estimation, EBP, and optimization with hundreds of DER on multiple feeders
  - Publish **final report** of the utility demonstration and key findings

DER Cyber Security WG

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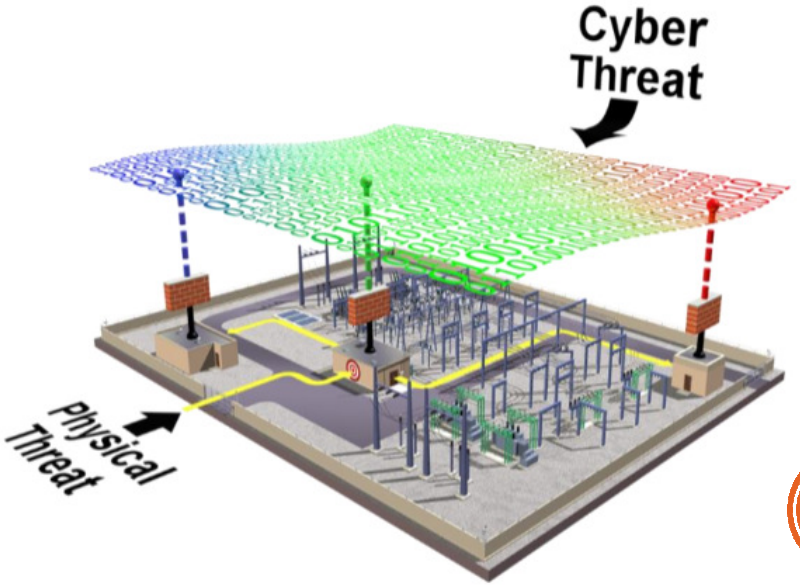
- The DER Cyber Security Working Group will bring together DER interoperability and cyber security experts to discuss security for DER devices, gateways, and other networking equipment, owned or operated by end users, aggregators, utilities, and grid operators.
- **Primary Goal: generate a collection of best practices that act as basis for (or input to) national or international DER cyber security standards.**
- Secondary Goal: facilitate DER cyber security discussions among stakeholders to exchange perspectives and gain broad buy-in from the industry.

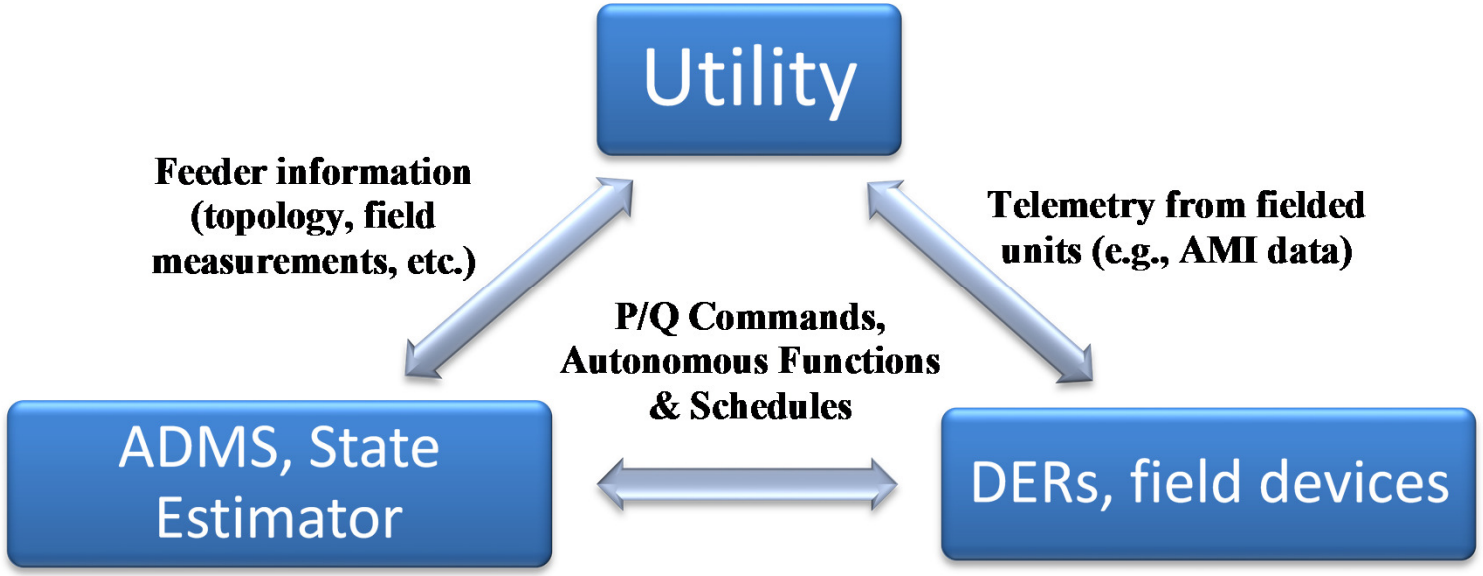


SUNSPEC ALLIANCE

Sandia National Laboratories

Standardized ADMS/DERMS Information Models

- Massive deployment of ADMS/DERMS systems requires **standardized communications between entities**, including consistent data models, communication protocols, transfer rates, etc.
- This project intends to recommend an **open-source standard for ADMS/DERMS systems** approved through the SunSpec Alliance.
  - Similar to the SunSpec Inverter Models and Orange Button Standards.



Cybersecurity & Interoperability

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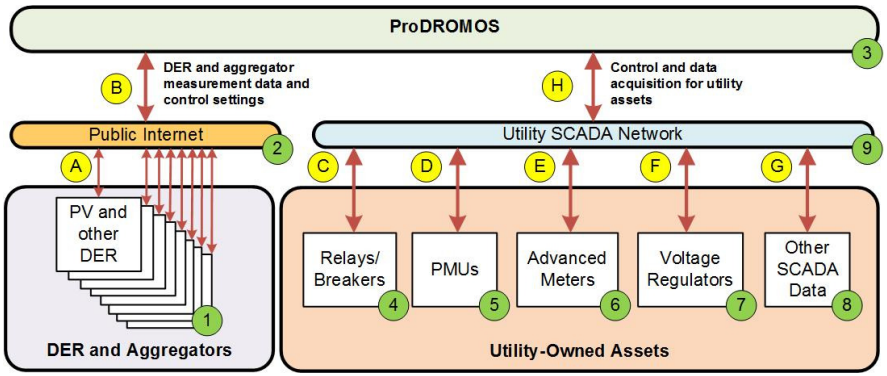
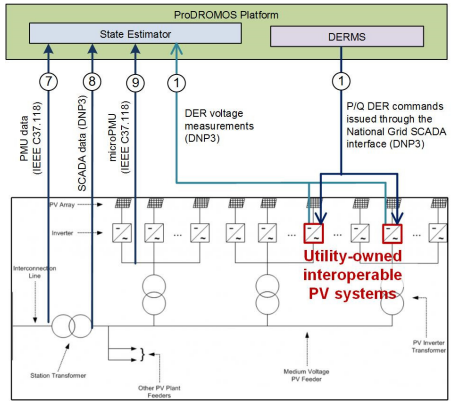
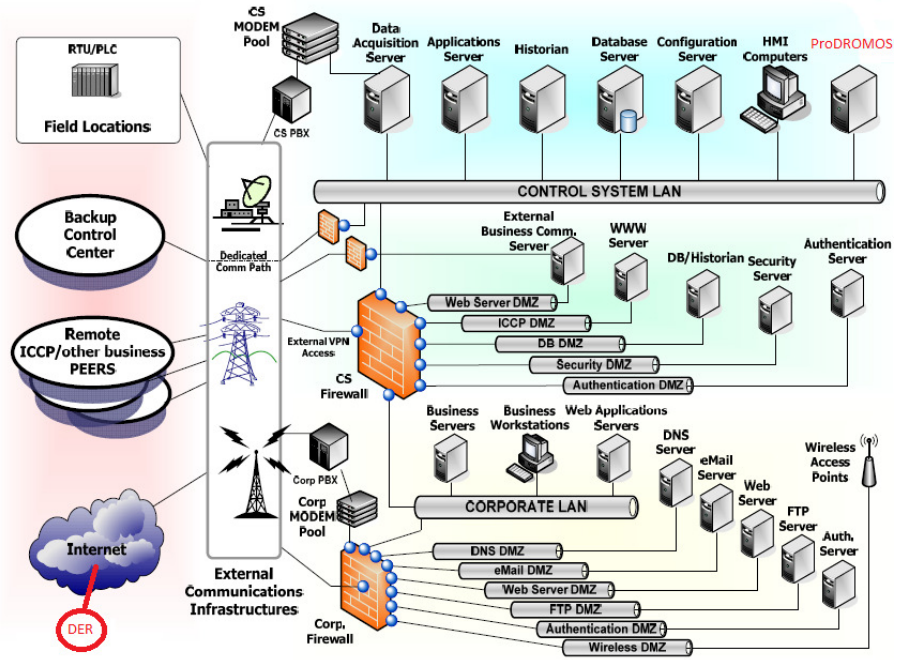
- Team has completed the Cyber Security and Interoperability Plans for the project.
  - Happy to share with other ENERGISE teams, but keep in mind this is a "plan" and will be updated over the course of the project.





Communication network is composed of multiple standardized protocols.



Risks & Mitigations

- **Risk**: Optimization over large design space will take too long. (Optimizing many groups of DER with multiple grid-support function options over a forecast horizon.)
  - **Mitigation**: Implement computational parallelization, dimension reduction, and high performance computing.

- **Risk**: Integrating hundreds of simulated interoperable DER devices in RT-Lab environment will require dozens of cores.
  - **Mitigation**: Aggregating DERs into single entities with higher nameplate P/Q settings will reduce the order of the simulation and maintain real-time results.

- **Risk**: Transferring Georgia Tech state estimation and optimization (research) code to commercial implementation may take a long time.
  - **Mitigation**: GT to assist as much as possible, providing DLLs and support products where appropriate.

- **Risk**: Data exchange between EPRI PV Simulator and real-time simulation may be too slow for estimation based protection.
  - **Mitigation**: Targeting realistic DER data rates with Data Bus (DBUS) UDP server architecture.