Voltage Regulation and Protection Assurance using DER Advanced Grid Functions

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SYSTEMS INTEGRATION

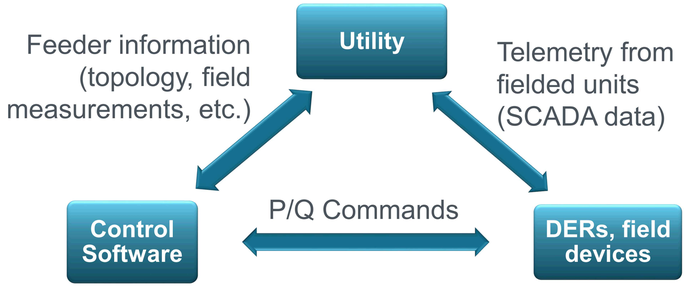
PROJECT OVERVIEW

This project has created open-source components for a commercial platform to address the spectrum of distribution circuit and DER management, including: state estimation, voltage regulation, protection, economic optimization, communications and cybersecurity.

This solution safely allowed PV penetrations of 50% or greater by providing real-time visibility into distribution circuits and optimizing the active and reactive power (P/Q) DER settings to meet voltage regulation, protection and economic objectives in the presence of forecast uncertainty.

PROJECT OBJECTIVES

- Provide real-time feeder visibility/visualization
- Operate DERs to keep feeder voltages within ANSI C84.1-2006 limits
- Maintain protection with high penetrations of DER on distribution circuits
- Minimize economic costs using multi-objective optimization
- Create information exchange recommendations
- Generate cyber security recommended practices

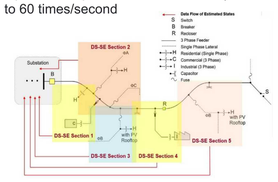


Developing a standardized information model for exchange between the utility, control systems, and field devices enables 3rd party DERMS integration.

TECHNOLOGY OVERVIEW

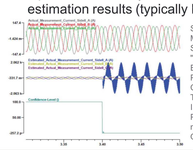
Georgia Tech and Sandia technologies released as open-source algorithms and incorporated them into a commercial software product developed by BPL Global. The core technologies being developed are:

1. Distribution System Distributed Quasi-Dynamic State Estimator
   - Generates the voltage profile and power flow estimation with scalable solution from feeder telemetry
   - Operates on partitioned distribution system with solutions at up to 60 times/second



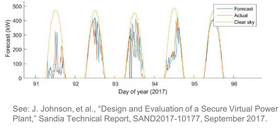
See: A.P. Meliopoulos, G. Cokkinides, B. Xie, C. Zhong, J. Johnson, "Full State Feedback Control for Virtual Power Plants," Sandia Technical Report, SAND2017-10178, September 2017.

2. Estimation-Based Protection
   - Detects faults and protects the system by isolating the faulted section of circuit
   - Signals reclosers, breakers, or other switching operations
   - Operates extremely fast after collecting state-estimation results (typically below 1 ms)



See: Y. Liu, A. P. S. Meliopoulos, R. Fan, L. Sun and Z. Tan, "Dynamic State Estimation Based Protection on Series Compensated Transmission Lines," in IEEE Transactions on Power Delivery, vol. 32, no. 5, pp. 2199-2209, Oct. 2017.

3. Persistence forecasting
   - Uses historical data and clear sky index to generate PV power forecast
   - 1-15-sec time-step with a 10-min horizon
   - Forecast uncertainty characterized by historical record to be used in the optimization



See: J. Johnson, et al., "Design and Evaluation of a Secure Virtual Power Plant," Sandia Technical Report, SAND2017-10177, September 2017.

4. Robust optimization taking into account forecast uncertainty
   - Construct an uncertainty set Ω for the DER power injections
   - Define DER power injections in terms of u^t

$$\Omega^t(\hat{X}^t, \delta^t, \delta^t) := \left\{ u^t \in \mathbb{R}^l : \sum_{i \in I} \frac{|u_i^t - \hat{X}_i^t|}{\delta_i^t} \le \delta^t, u_i^t \in [\hat{X}_i^t - \partial_i^t, \hat{X}_i^t + \partial_i^t], \forall i \in I \right\}, \Omega := \prod_{t \in T} \Omega^t$$

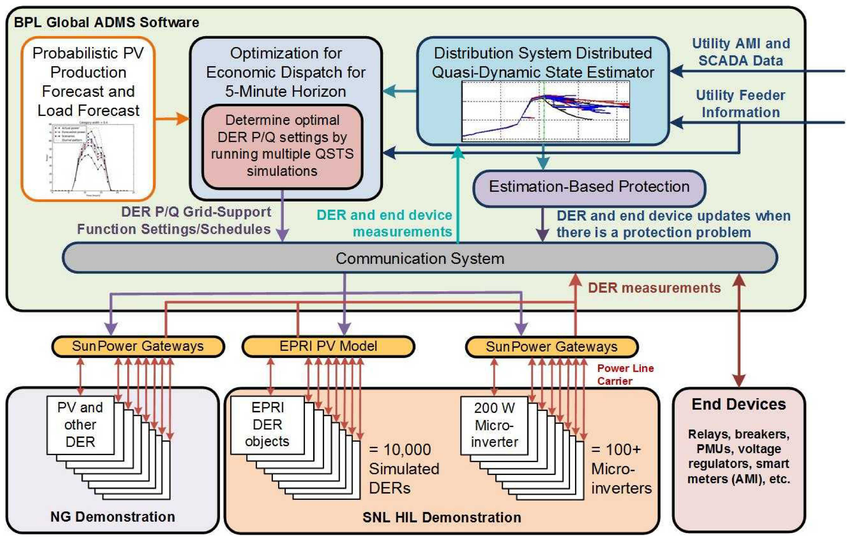
where I is the set of all DERs with uncertain injections for time intervals in T
u^t: vector of uncertain DER power injections
$\hat{X}_i^t$: nominal value of the DER power injection
$[\hat{X}_i^t - \partial_i^t, \hat{X}_i^t + \partial_i^t]$: range of uncertainty
δ^t: Budget of uncertainty set

See: D. Bertsimas, E. Litvinov, A. Sun, J. Zhao, and T. Zheng, Adaptive Robust Optimization for the Security Constrained Unit Commitment Problem, IEEE Transactions on Power Systems, 28, 1, 52-63, 2013.

SYSTEM ARCHITECTURE AND OPERATIONS

Programmable Distribution Resource Open Management Optimization System (ProDROMOS)

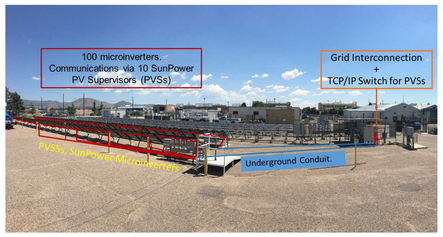
(Prodromos is Greek for "forerunner" and the prodromoi were a light cavalry army unit in ancient Greece used for scouting missions.)



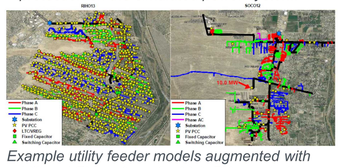
1. Distribution System Distributed Quasi-Dynamic **State Estimator** (DS-DQSE) ingests feeder telemetry, DER and customer data, and generates the voltage profile and power flow estimation.
2. The **Estimation-Based Protection** (EBP) scheme detects faults and protects the system by isolating the faulted section of the distribution circuit by recloser/breaker/switching operations.
3. The **forecasting** component provides short-term (e.g., 10 minute) forecasts of PV power output and load using recent system states and statistical irradiance modeling in conjunction with PV performance models.
4. A **dispatch optimization engine** determines the necessary active and reactive (P/Q) power settings for groups of DERs to maintain voltage and distribution protection systems for the next time period (~1-5 minutes) considering the economic impact of curtailment and non-unity power factor operations.
5. The **communications system** uses the SCADA and DER control network to update DER operations and get new data from the power system.

DEMONSTRATION WITH POWER HARDWARE-IN-THE-LOOP

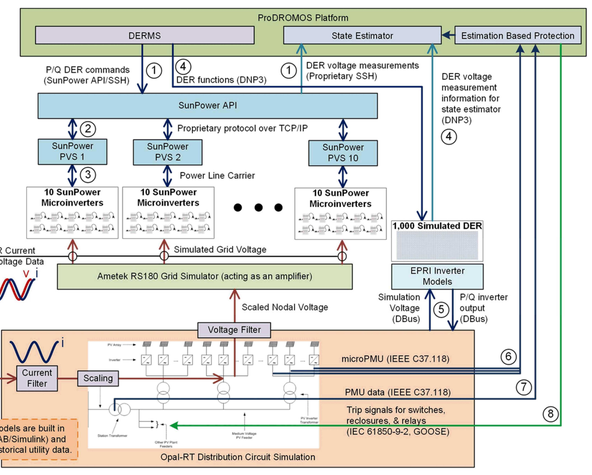
The ProDROMOS system was demonstrated using a power hardware-in-the-loop system (PHIL) at the Distributed Energy Technologies Laboratory (DETL) at Sandia and in a field demonstration on a National Grid feeder with a utility-scale PV installation.



100 Microinverter installation at DETL. The active and reactive power of each of the devices can be changed to provide voltage regulation and protection on the simulated power system.



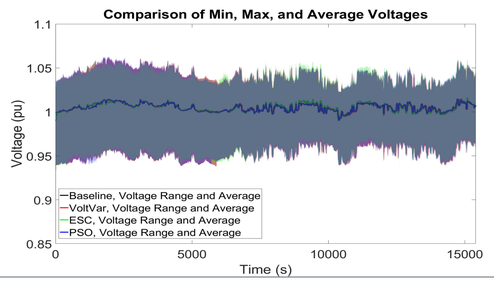
Example utility feeder models augmented with additional PV systems for high PV penetration simulations with the ProDROMOS system.

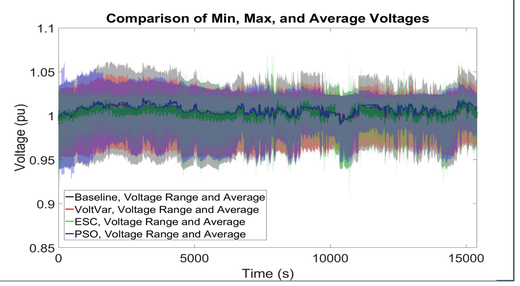


PHIL power and information flows with the ProDROMOS system controlling real and simulated DER.

Comparison of Voltage Regulation Approaches

Different voltage regulation results for the National Grid feeder model.





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