2017 ADMS Program
Steering Committee Meeting

Community Control of Distributed Resources for Wide Area Reserve Provision

Presenter: Jason MacDonald, LBNL
PI: Duncan Callaway, LBNL (joining by phone)

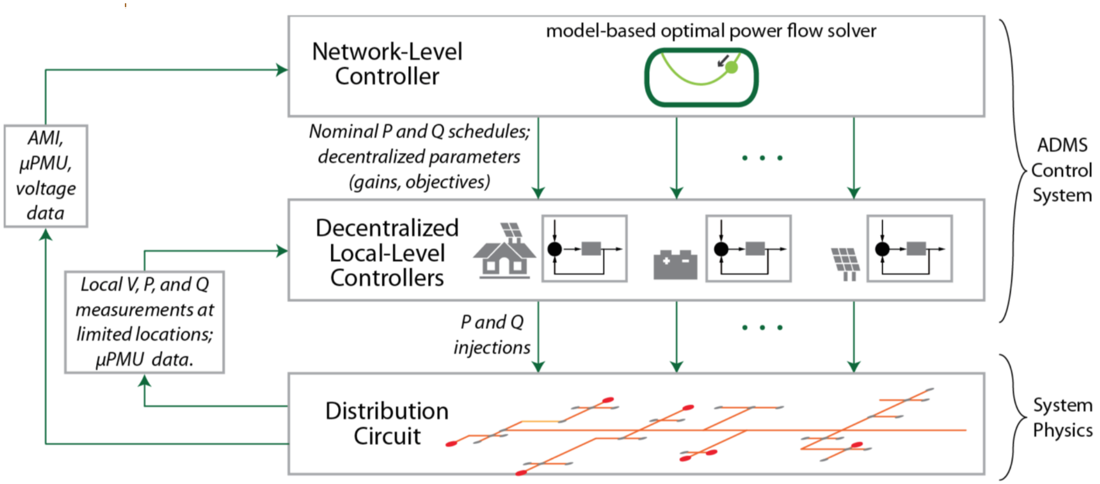
October 11, 2017

Community Control of Distributed Resources for Wide Area Reserve Provision

Objectives & Outcomes

Objective: Develop, refine and test network-aware DER controls to elevate load buses to the status of generator buses from the perspective of transmission operations.

Outcome: Open source control algorithms. Implementation on commercial DMS system and demonstration via HIL testing.



Technical Scope

- Tools for spatiotemporal forecasting of DER output
- New distribution system operations planning, including battery state of charge management
- New real time decentralized optimization tools
- Hardware-in-the-loop tests of PV and battery systems for network management
- Implementation on industry partner's existing DER management platform
- Assessment of value for volt-VAR optimization and delivery of transmission level services

Life-cycle Funding Summary ($K)

FY16, authorized	FY17, authorized	FY18, requested	Out-year(s)
$1,100	$906	$1,075	

Project Context

Context: Increasing build-out of distributed energy resources interfacing with distribution systems via power electronics

There is growing interest in using these resources for

- ***Distribution system*** optimization (CVR, VVO)
- Engaging with ***transmission system*** energy and reserve markets

During 2016 staff from CAISO, PG&E, SDG&E and SCE were part of a working group on “T-D Interface Coordination” to identify needs and develop recommendations toward developing a high-DER T-D coordination framework.[1]

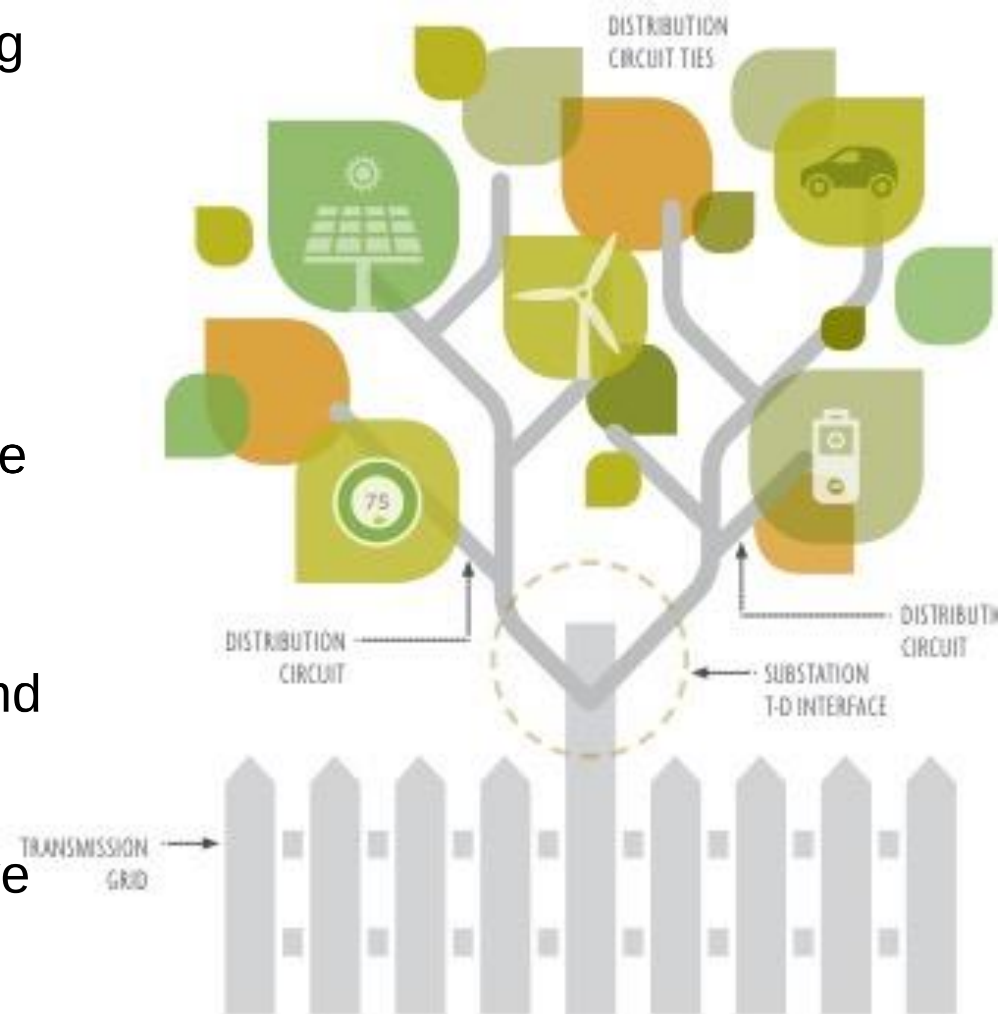
This group expressed uncertainty regarding whether these resources can be engaged for use in one system does not negatively impact the other

[1]This working group was convened by More Than Smart

Project Context

TD working group issues: Using DER for transmission *and* distribution services faces performance and reliability uncertainties:

- ISO dispatch DERs without knowing impact on the distribution system or if they are feasible
- Currently there are limited methods to forecast how DER participation affects net load and voltage, at the ***T-D interface***, and
- The DO does not currently have the same level of visibility, control and situational awareness of DERs as the ISO does with transmission connected generators.



"COORDINATION OF TRANSMISSION AND DISTRIBUTION OPERATIONS IN A HIGH DISTRIBUTED ENERGY RESOURCE ELECTRIC GRID" JUNE 2017. PREPARED BY STAFF OF CAISO, PG&E, SCE, SDG&E WITH SUPPORT FROM MORE THAN SMART

Project Context: Anticipated Benefits

- Electricity consumers: reduce costs and improve power quality
- Distribution companies: provide new network and DER management products and opportunities to reduce costs in or even profit from transmission-level markets
- Transmission operators: Facilitates greater penetration of variable renewable generation, additional options for flexibility, additional market participants
- Industry: Open-source algorithms for distribution network management products

Team Collaboration

LBNL PIs:
Duncan Callaway
NREL PI: *Brian Johnson*
SNL PI: *Cliff Hansen*

BERKELEY LAB

- Load forecasting
- Network level control
- Local level control
- Simulation and HIL testing

NREL – NATIONAL RENEWABLE ENERGY LABORATORY

- Network level control
- Network / local level control integration

Sandia National Laboratories

- Solar forecasting tools
- Simulation and HIL testing

smarter grid solutions

- ADMS solution provider
- Interoperability and platform implementation

WATER | ENERGY | LIFE – CITY OF RIVERSIDE PUBLIC UTILITIES

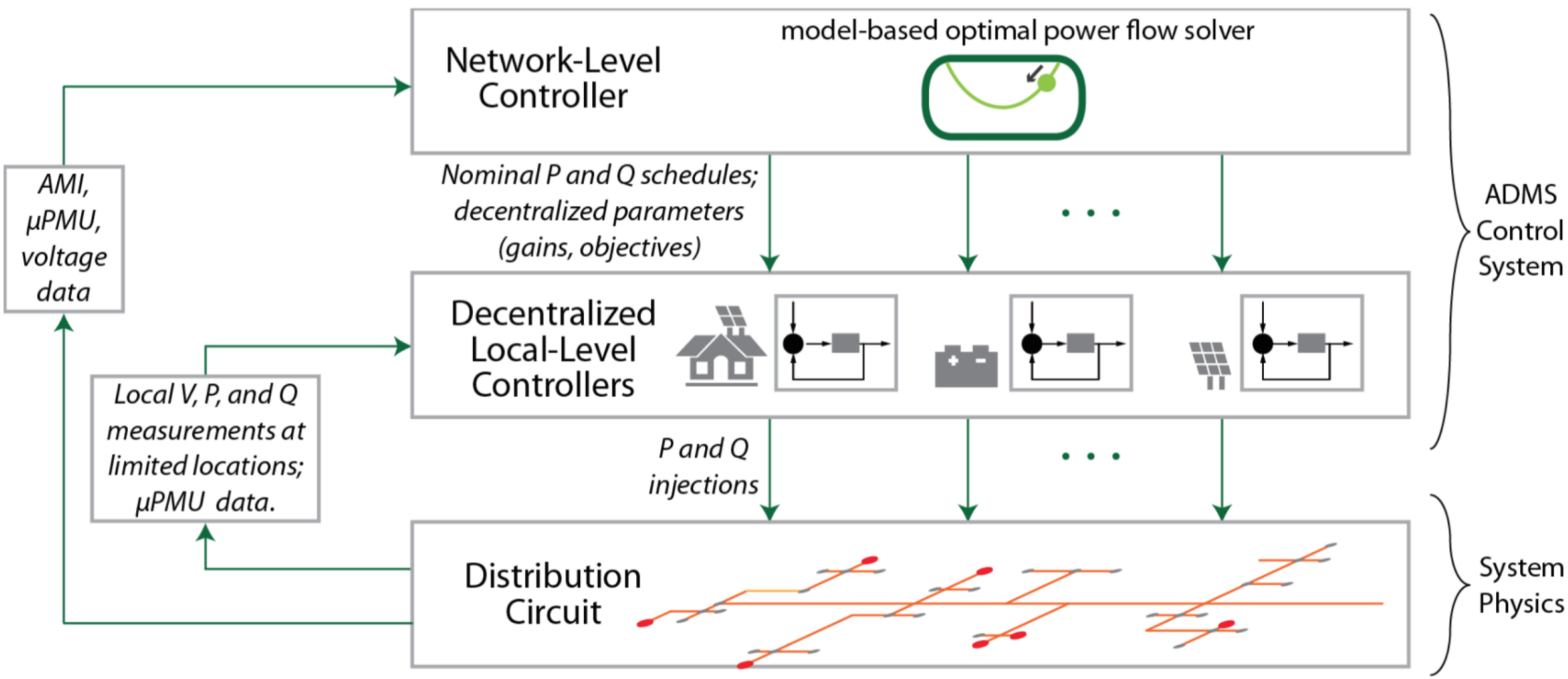
- SCADA and uPMU data
- Network model and demo site

Project status: Timeline

- Three year project, in its second year.
  - First year: Initial algorithm development
  - Second year: translation to HIL testing
  - Third year: further HIL testing and refinement
- Original project budget: $3.25M
  - Second year budget reduced by $170k, scope reduced to run HIL tests without power hardware and on simplified network model
  - Spending is on track

Five tasks

1. Forecasting and offline optimization
2. Real time control algorithms
3. Interoperability and platform implementation
4. Simulation and hardware in the loop testing
5. Project Management and Evaluation



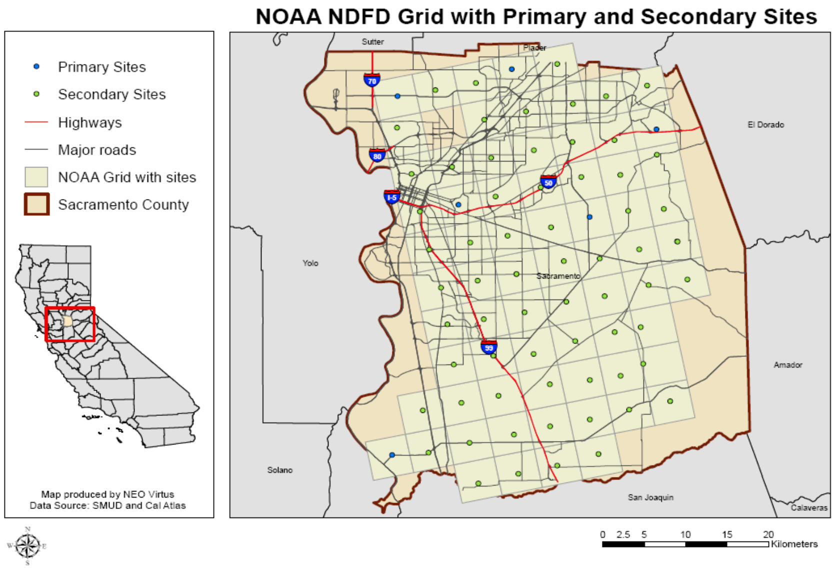
Task 1: Forecasting

Two resolutions and horizons :

- Hourly, +24h to +60h : derive from gridded weather forecasts
- ~5 minute, now to +2h : data-driven from meters
  - Alternatives to statistical approaches require dedicated infrastructure (e.g., sky cameras) or satellite imagery processing (coarse resolution)
- Apply state-of-art spatio-temporal model to forecasting
  - Accounts for local (time and space) correlations among locations
  - Adaptive to changing weather conditions
- Both resolutions will explicitly include representations of uncertainty in energy and power for use in developing chance constraints for the optimizations

Task 1: Forecasting accomplishments

- For testing and validation:
  - SFCAR implemented in R
  - Python wrapper for data management, qualification
  - Leverages data qualification toolset in pvlib-python, pecos
- Forecasting components intended for inclusion in open-source pvlib-python
- Validation with SMUD sensor network in progress



Task 1: Offline network optimization

- Objective: optimize the operation of DER and energy storage devices in the distribution system to minimize certain objective function (such as total cost, or total energy consumptions)
- Challenge in distribution network optimization
  - Guarantee system performance under the presence of high uncertainties in DER and uncontrollable loads
- Our approach
  - Use the energy storage to mitigate the uncertainties
  - Formulate a chance-constrained optimization problem
- Note, we assume forecast errors and distribution model errors are unavoidable
  - Online network optimization, Task 2, overcomes this
  - The offline phase is a "planning" step to minimize costs and manage the probability that network constraints will be violated

Task 1: Offline network optimization formulation

$$
\begin{aligned}
\underset{U}{\text{minimize}} \quad & \sum_{t \in \mathcal{T}_s} c_{p,t}(P_{0,t} - P^*_{0,t})\Delta t \\
\text{subject to} \quad & P_i = P_{i-1} - P_{l,i} + u_i + P_{pv,i} \\
& Q_i = Q_{i-1} - Q_{l,i} + Q_{pv,i} \\
& V_i^2 = V_{i-1}^2 - 2(r_i P_{i-1} + x_i Q_{i-1}) \\
& \mathbf{P}\left(u_i + \alpha_i \sum_j w_j \leq u_{max,i}\right) \geq \eta \\
& \mathbf{P}\left(u_i + \alpha_i \sum_j w_j \geq u_{min,i}\right) \geq \eta \\
& \mathbf{P}\left(f_{v,i} + \sum_j k_{i,j} w_j \leq V^2_{max,i}\right) \geq \eta \\
& \mathbf{P}\left(f_{v,i} + \sum_j k_{i,j} w_j \geq V^2_{min,i}\right) \geq \eta \\
& SOC_{i,t+1} = SOC_{i,t} + U_{i,t}\Delta t \\
& \mathbf{P}\left(SOC_{i,t} + \alpha_i \sum_j w_{j,t}\Delta t \leq SOC_{max}\right) \geq \eta \\
& \mathbf{P}\left(SOC_{i,t} + \alpha_i \sum_j w_{j,t}\Delta t \geq SOC_{min}\right) \geq \eta \\
& SOC_N = SOC_{end}
\end{aligned}
$$

Power flow equations

Chance constraint for energy storage power limits

Chance constraint for bus voltage limits

Chance constraint for energy storage SOC limits

Task 1: Offline network optimization

- Currently in the process of integrating chance constrained formulation into GAMS (optimization solver)
- Chance constraints will be formulated with output from solar and load forecasts.

Task 1: Additional accomplishments

- Developed a stochastic framework for determining which locations in distribution feeders are most receptive for Volt/VAR or Volt/Watt control (or both) under high solar penetration
- Included uncertainties in load and solar irradiance in a robust framework
- Improved upon the default Volt/VAR settings in the IEEE 1547.8 standard by preventing oscillations in voltage and reactive power
- Real-time control with periodic adjustment of Volt/VAR/Watt settings to account for shifting system conditions

Task 1: FY 2018

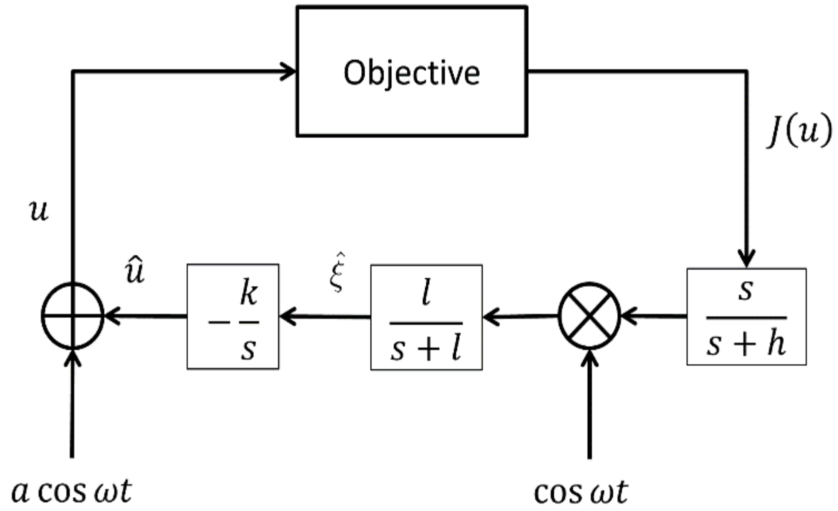
Refine forecasting and control with emphasis on streamlining for implementation

- Ensure execution with open-source code or readily available commercial solvers
- Forecasting: Provide reference implementations of data-driven forecasting methods that offer a range of capability for temporal and spatial resolution.
- Optimization: Drive toward computing times well under the smallest optimization time step (e.g. 5 minutes) for network sizes of several hundred nodes.

Due Date	Milestone Type	Milestone Description
Dec-17	Process milestone	Task 1: Publish open source forecasting code (SNL)
Sep-18	Process milestone	Task 1: Implement distribution network optimization on RPU feeder model with commercial solver; demonstrate computing time well under smallest optimization time step (NREL/LBNL)
Sep-18	Intermediate Deliverable	Task 1: Annual report

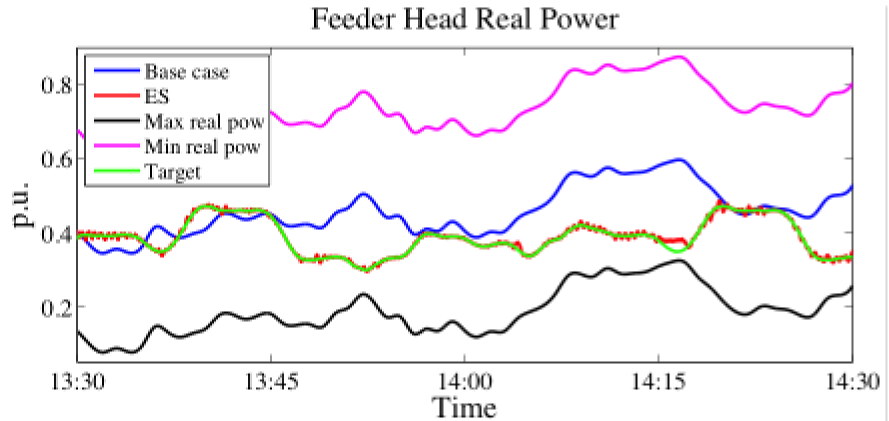
Task 2: Real time control algorithms

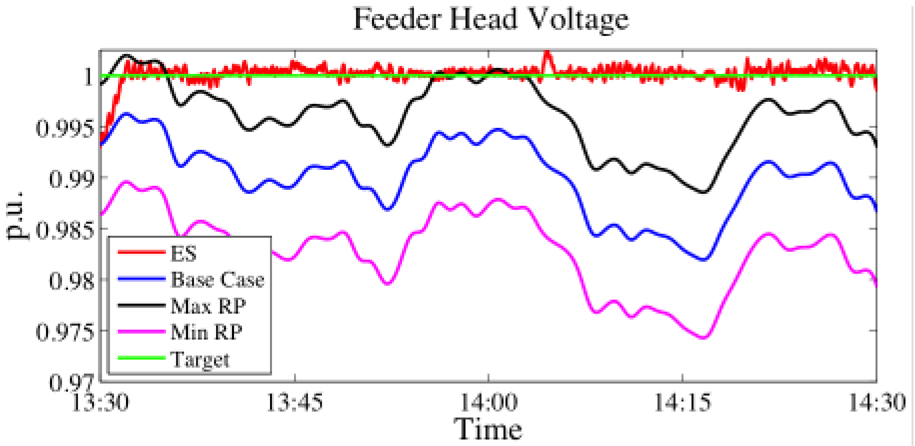
- Objective to develop distributed control algorithms that
  - Operate on the basis of setpoints from the offline optimization stage.
  - Ensure optimal or near-optimal distribution performance based on the extremum seeking (ES) control approach.
- The ES control approach is a data-driven approach
  - DER introduce small perturbations into system to recover sensitivities in real time
  - On the basis of those sensitivities, resources drive output to optimal points
  - Network models and information about injections and extractions at other points in the network not required
- SCADA information from utility partner, Riverside Public Utility, will be incorporated to create filters for the ES control.



Task 2 Accomplishment: Real time control algorithms

- IEEE 37 node test system with additional transmission impedance (to generate voltage response at feeder head)
- 6 ES-controlled DER with real and reactive power control capabilities
- Objective:
  - Regulate voltage at feeder head
  - Track PJM reg D signal at feeder head
  - Regulate local voltages in network
- Simulation results demonstrate ES control can allow a load bus to mimic generator controls at the T-D interface





Task 2: Additional accomplishments

- Result showing convexity of net load tracking problem in neighborhood around the performance targets
  - This facilitates theoretical guarantees of performance of decentralized ES control algorithm
- Results are independent of the choice of objective function (i.e. they are valid for activities other than reference tracking of substation states and feeder voltage regulation).
  - This opens the possibility to use ES control for other applications
- Preliminary work extending ES control to manage battery storage devices
  - Developed new ES feedback control block diagram for storage devices
  - Completed preliminary stability proof

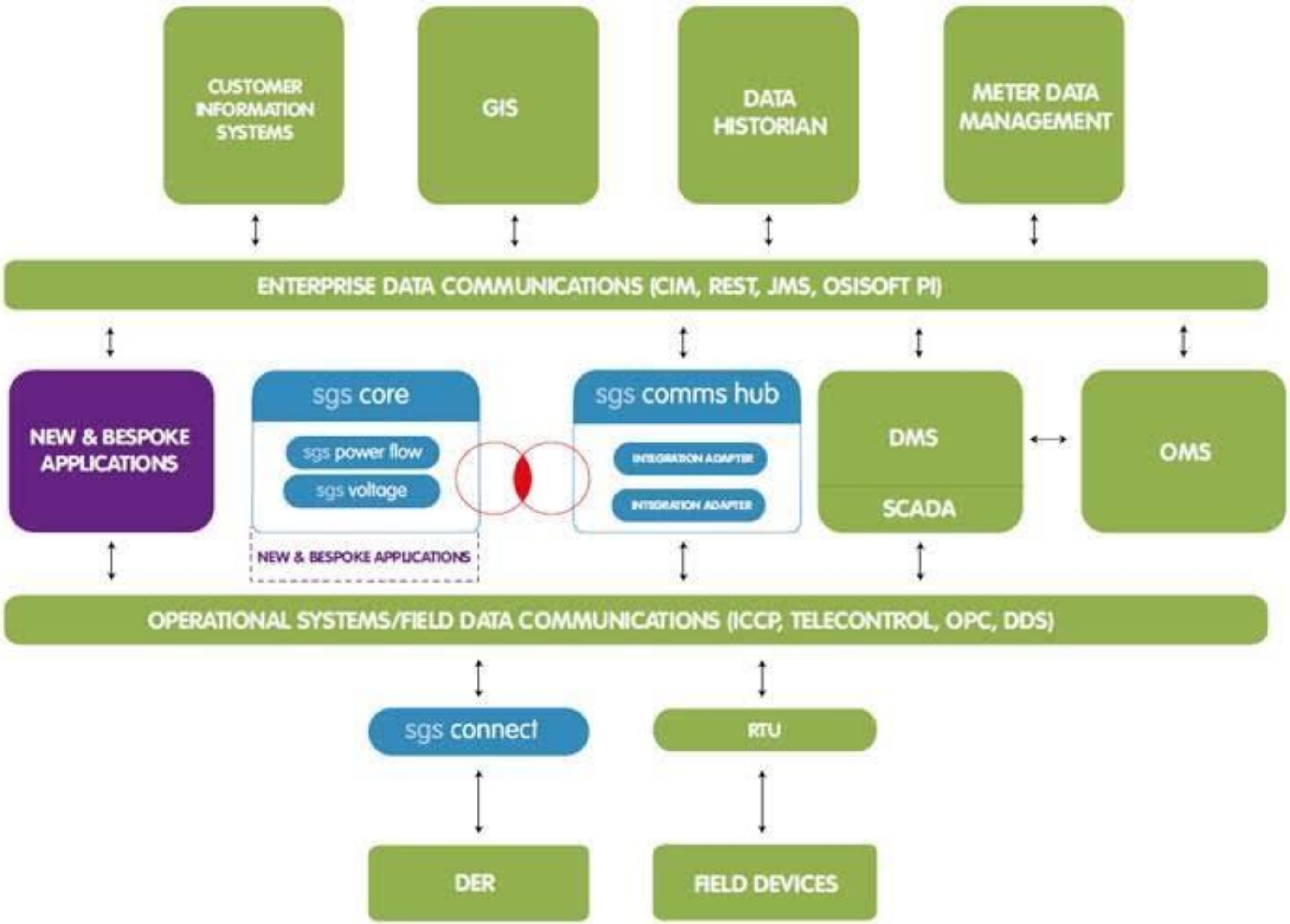
Task 2: FY 2018

Task 2: Real time control algorithms.

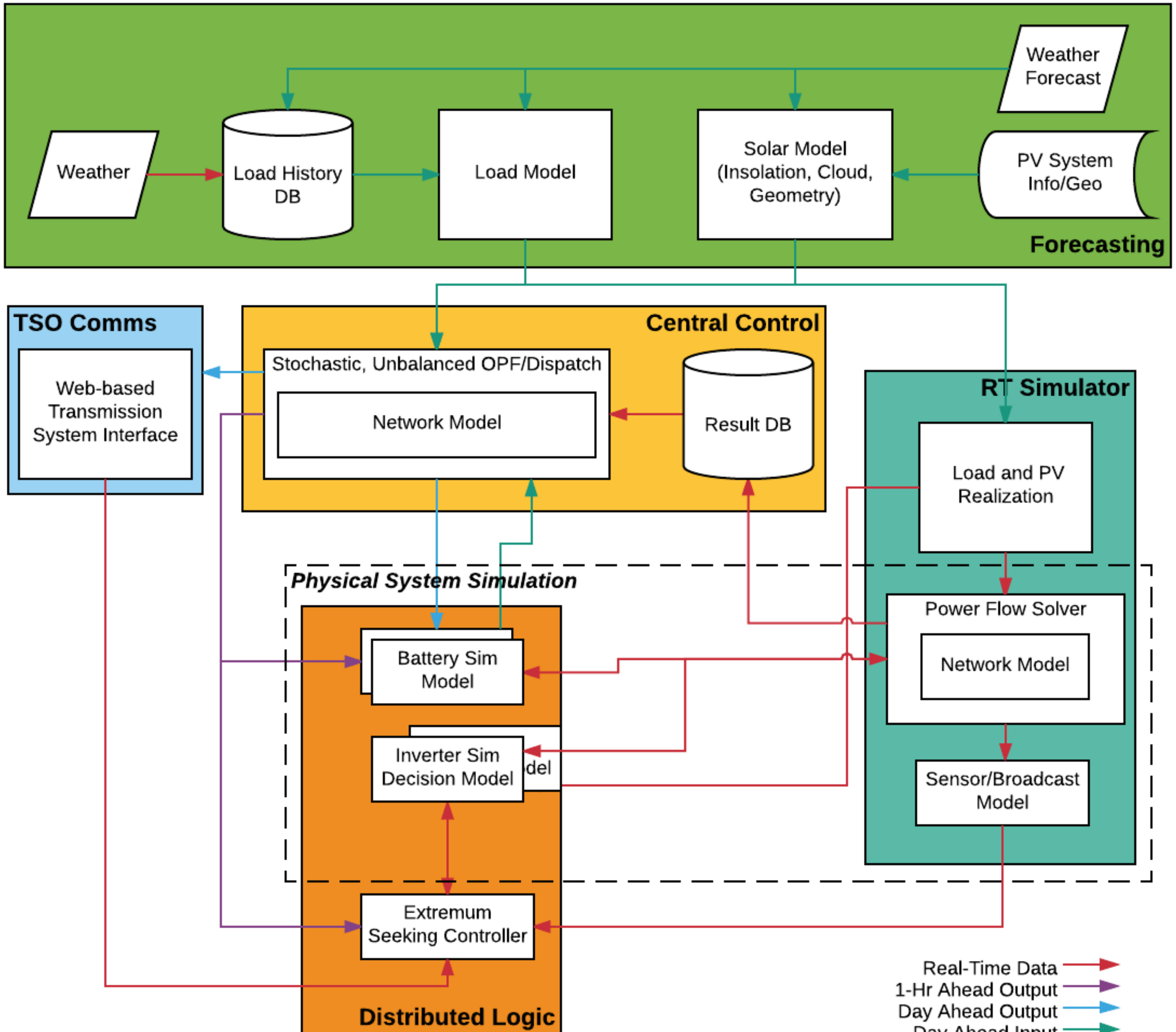
- Refine distributed and decentralized ES approaches with focus on streamlining implementation.
- Specific goal is to generate models of decentralized optimization actions to be integrated into Task 1’s network level optimization algorithms.

Due Date	Milestone Type	Milestone Description
Dec-17	Process milestone	Task 2: generate models of ES action for network level optimization decision criteria (LBNL)
Mar-18	Process milestone	Task 2: extend ES control formulation to include electric storage resources (LBNL)
Sep-18	Intermediate Deliverable	Task 2: Annual report

Task 3: Smarter Grid Solutions Platform Architecture



Task 3: Scope of SGS integration into ADMS project



Task 3: FY 2017 and 2018

FY 2017 accomplishments:

- Completed Design Specification
- Network Model for Real-Time Simulation
- Integrated and tested real time optimization logic into platform
- Integration of GAMS optimization engine using Java API
- Preliminary OPAL-RT testing

FY 2018 Focus:

- Refine application container, and refine and complete communications hub.
- Support OPAL-RT integration for HIL testing

Due Date	Milestone Type	Milestone Description
Dec-17	Process milestone	Task 3: Successful integration of control algorithms into SGS platform for HIL demonstration (SGS)
Feb-17	Process milestone	Task 3: Successful integration of data streams into SGS platform for HIL demonstration (SGS)
Sep-18	Intermediate Deliverable	Task 3: Annual report

Task 4: Simulation and hardware in the loop testing

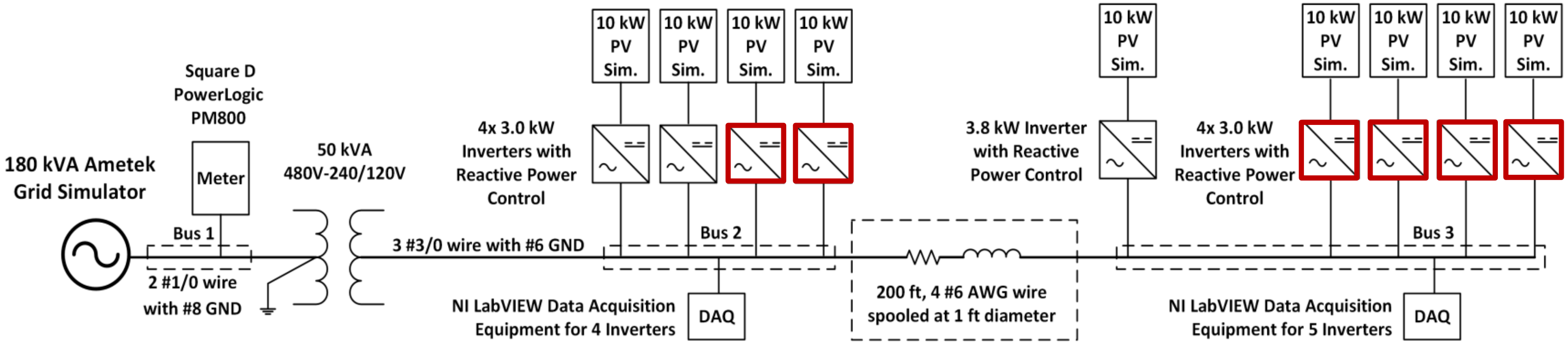
- This task includes
  - Power hardware testing at SNL for ES proof of concept
  - Hardware-in-the-loop testing at LBNL
    - Opal-RT simulator
    - Instance of SGS active network platform running offline and real time optimization algorithms
- Original HIL scope covered power hardware in the loop testing on RPU feeder model
  - With budget reduction, scope modified to control hardware testing only, on 13 node feeder model.

Task 4: Key accomplishments

- Demonstrated ES voltage regulation in SNL hardware testing environment
- Configured LBNL FLEXLab OPAL-RT test environment for HIL testing
- RPU uPMU data analysis to identify frequency regions for ES probe

Task 4: Power Hardware Test Configuration

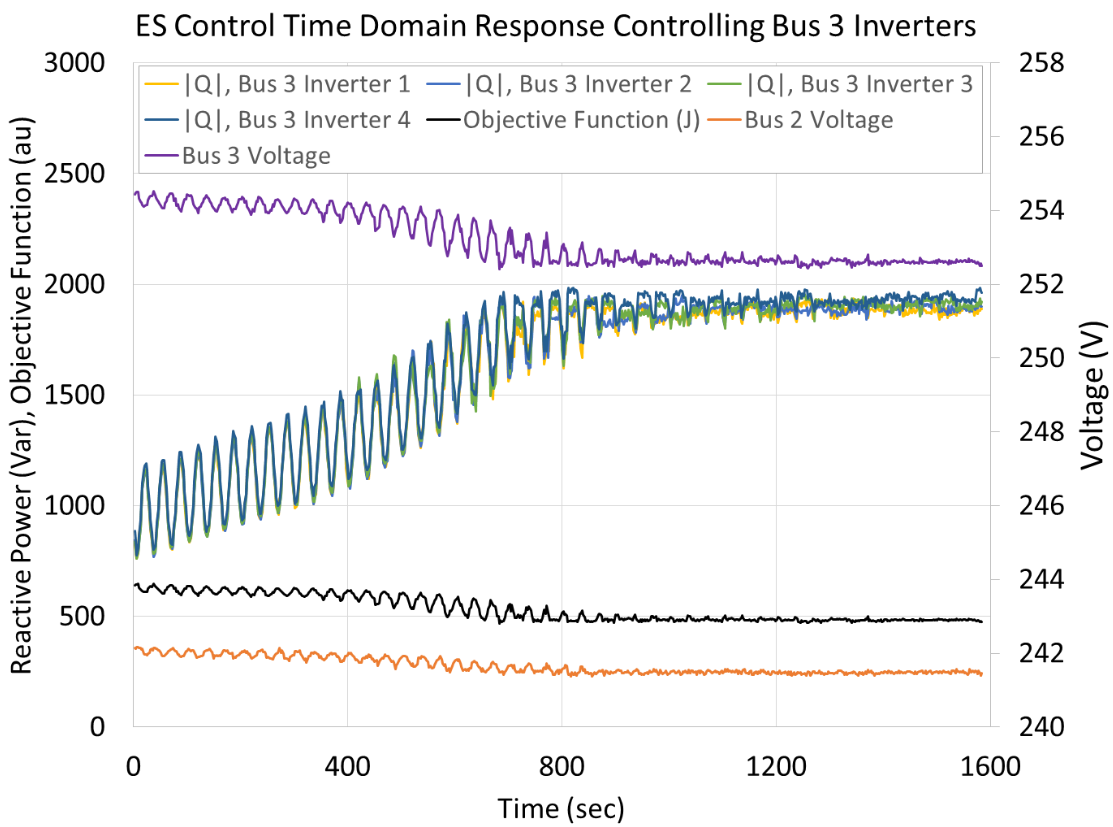
- Created physical feeder configuration in the SNL Distributed Energy Technologies Laboratory (DETL)



Six inverters were controlled in the experiments.

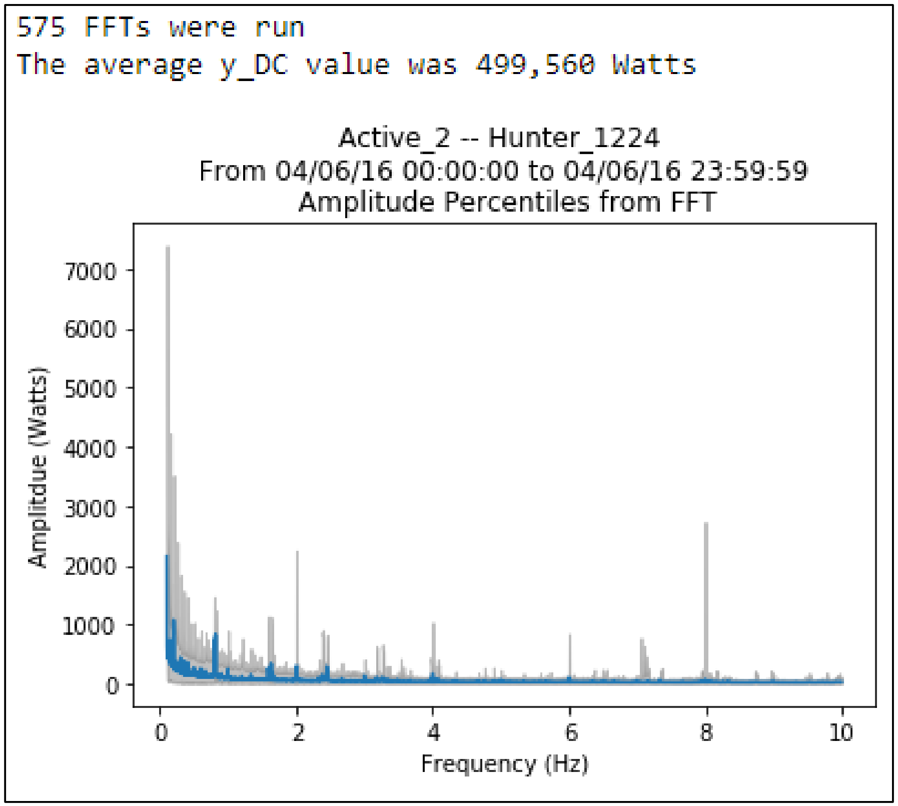
Task 4 accomplishment: Positive ES Control Results

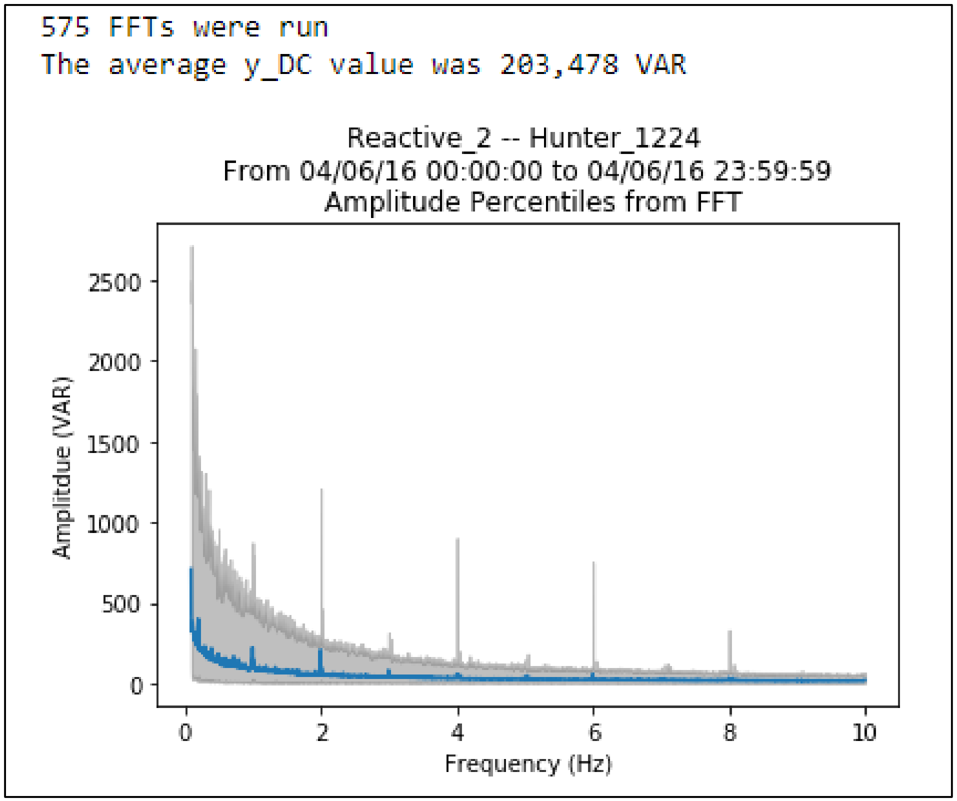
- Implementation of ES Control
  - Results show DER track towards global optimum $J = \Sigma(V_{DER}-V_{nom})^2$



Task 4: uPMU data analysis

- FFT plot indicate there is substantial "room" in frequency domain for ES controllers to probe a feeder at low amplitude
  - tens to hundreds of watts in both real and reactive power





Task 4: FY 2018

Task 4: Simulation and hardware in the loop testing.

- Implement HIL test with planned completion in FY19.
- End of FY18 objective is to have HIL test operating on Riverside Public Utility feeder model in OpalRT with SGS control hardware, pending restoration of funds

Due Date	Milestone Type	Milestone Description
Mar-18	Process milestone	Task 4: Preliminary power hardware ES tests complete (SNL / LBNL)
Mar-18	Process milestone	Task 4: Control hardware in the loop tests complete with 13 bus network model (SGS / LBNL)
Sep-18	Process milestone	Task 4: Power hardware in the loop tests initiated with RPU network model (SGS / LBNL)
Sep-18	Intermediate Deliverable	Task 4: Annual report

Task 5: Management and Evaluation: FY 2018

- Evaluate transmission level benefits based on available data and simulation results.
  - Our specific goal is to implement a transmission-level network / market optimization model that enables comparison of transmission-level operational costs with and without this project’s community control approach.
  - We will focus on evaluation in the California footprint with specific emphasis on understanding the benefits of control actions in the RPU footprint.

Due Date	Milestone Type	Milestone Description
Sep-18	Process milestone	Task 5: Quantification of benefits of voltage control from load bus at transmission level (LBNL)
Sep-18	Process milestone	Task 5: Quantification of benefits of frequency regulation from load bus (LBNL)
Sep-18	Intermediate Deliverable	Task 5: Annual report

Project risks in FY 2018

- Risk: We are continuing to develop representation of ES in offline planning model
  - The planning model can work without this, however we anticipate improved performance if the representation can be integrated
- Risk: Solar data for forecasting and HIL simulation
  - We have access to solar data for locations other than RPU footprint
  - However we have positive indications from a large solar integrator in California that high temporal and spatial PV data can be made available
- Risk: HIL testing will be first Opal-RT effort at LBNL
  - SGS were involved in recent NREL HIL effort and have deep experience with the Opal-RT system; SGS visiting LBNL in December to configure.

Tech transfer – Patents and Papers

- Patents
  - K. Baker, A. Bernstein, and E. Dall'Anese, "Network-Cognizant Voltage Droop Control," Patent Pending.
- Papers
  - Arnold, D.B., Negrete-Pincetic, M., Sankur, M.D., Auslander, D.M. and Callaway, D.S., 2016. Model-free optimal control of var resources in distribution systems: An extremum seeking approach. IEEE Transactions on Power Systems, 31(5), pp.3583-3593.
  - Arnold, Daniel B., et al. "Model-Free Optimal Coordination of Distributed Energy Resources for Provisioning Transmission-Level Services." IEEE Transactions on Power Systems (2017).
  - K. Baker, A. Bernstein, C. Zhao, and E. Dall'Anese, "Network-cognizant Design of Decentralized Volt/VAR Controllers," Innovative Smart Grid Technologies (ISGT), 2017.
  - K. Baker, A. Bernstein, E. Dall'Anese, and C. Zhao, "Network-Cognizant Volt- age Droop Control for Distribution Grids," IEEE Transactions on Power Systems (to appear).
  - J. Johnson, S. Gonzalez, and D.B. Arnold, "Experimental Distribution Circuit Voltage Regulation using DER Power Factor, Volt-Var, and Extremum Seeking Control Methods," IEEE PVSC, Washington, DC, 25-30 June, 2017.
  - J. Patrick, J. Harvill, C. Hansen (2016), A semiparametric spatio-temporal model for solar irradiance data, Renewable Energy 87, pp. 14-30.

Tech transfer – Industry exposure

- SGS is a central project partner; though code is open source, at project conclusion the framework will be integrated into their commercial system
- RPU a project partner here and for follow-on ENERGISE project
  - Deployment of this ADMS an aspect of that project
- This ADMS system serves at basis for recent GMLC “GRIP” award led by SLAC
  - Google, SCE, Tesla, NRECA are key project partners
- We are participating in California T-D interface working group
  - CAISO, PG&E, SCE, SDG&E also participate

Contact information

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Back-up Slides

Include any back-up slides you would like to provide to the Steering Committee members and DOE program managers for additional information. The back-up slides will not be shared with others, unless specifically stated by the presenter.