GRID MODERNIZATION INITIATIVE
RDS Review Day 2019
CleanStart DERMS 1.5.5

EMMA M. STEWART (LLNL)
+1: JASON FULLER (PNNL)

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CleanStart DERMS 1.5.5
High-Level Project Summary

Project Description

Develop and implement a DER Management System integrated application, which provides a separate communications, analytics and control layer, purely for a black-start and restoration application

Solution will demonstrate the start of a microgrid following an outage (cyber or physical)

Project Objectives

- ✓ Minimize the outage time for the maximum number of customers using the greatest contribution from distributed and clean energy resources
- ✓ Implement methods for coupling and validation of predictive analytics and advanced controls for resilience
- ✓ Provide support services from DER back to the transmission system during critical outages
- ✓ Demonstrate a CEDS funded cybersecurity technology showing integration with the resilient DER architecture (CES-21/SSP-21)

Value Proposition

- Black start and restoration at present is a centralized bulk system driven solution whereas DER is by nature decentralized
- Key innovations
  - DER controls as a mechanism for black start and restoration
  - Cross utility coordination and effective useful information/resource transfer
- Product will be transformational to utilities experiencing a rapid DER influx, considering both controlled and uncontrolled resources as part of the resilient resources to be utilized in widescale events

CleanStart DERMS
Project Team

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

City of Riverside Public Utilities — Lead Demonstration Utility + Cost Share

Lawrence Livermore National Laboratory — Lead lab – device control and analytics integration

Pacific Northwest National Laboratory — Simulation and implementation

Los Alamos National Laboratory — Control algorithm development

OSIsoft — OSISoft – Data Integration

Xendee — Microgrid Design

Smarter Grid Solutions — DERMS technology provider + Cost Share Provider

PROJECT FUNDING			
Lab	Year 1	Year 2	Year 3
LLNL	$1009k	$1209k	$1064k
PNNL	$460k	$210k	$190k
LANL	$285k	$290k	$285k
Subs (through LLNL budget)	$492k	$683k	$547k
Cost Share (through Subs)		$1592k	
Total	$1754k	$1709k	$1539k

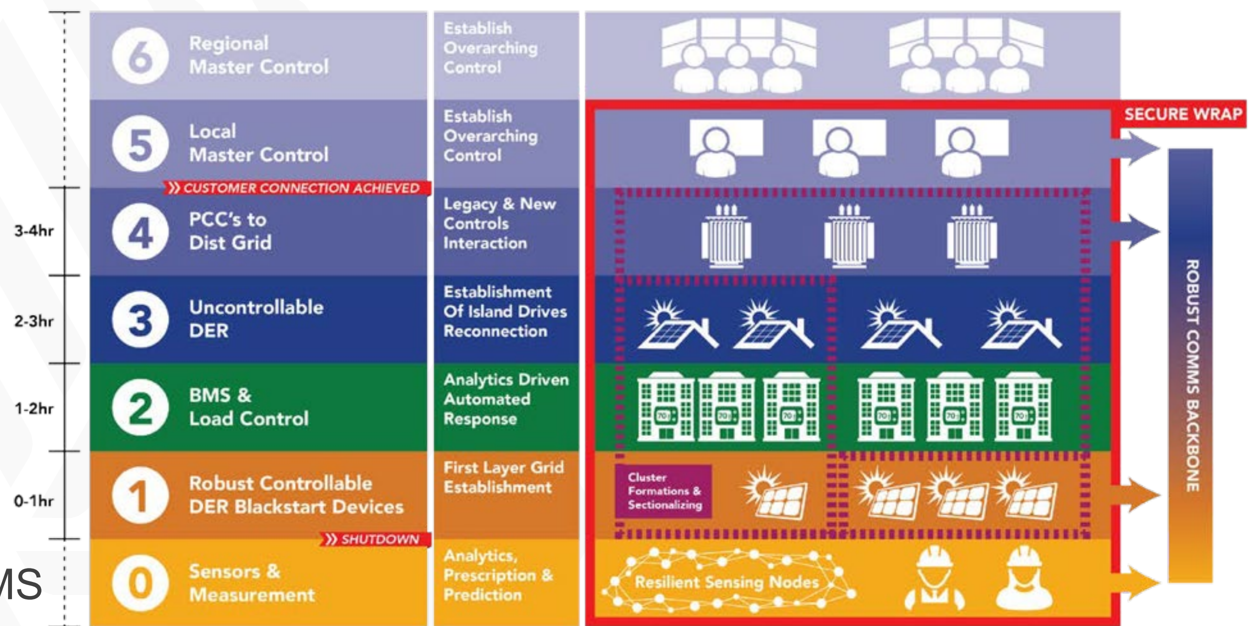
UC Riverside

PG&E — HIL Testing

11/13/2019

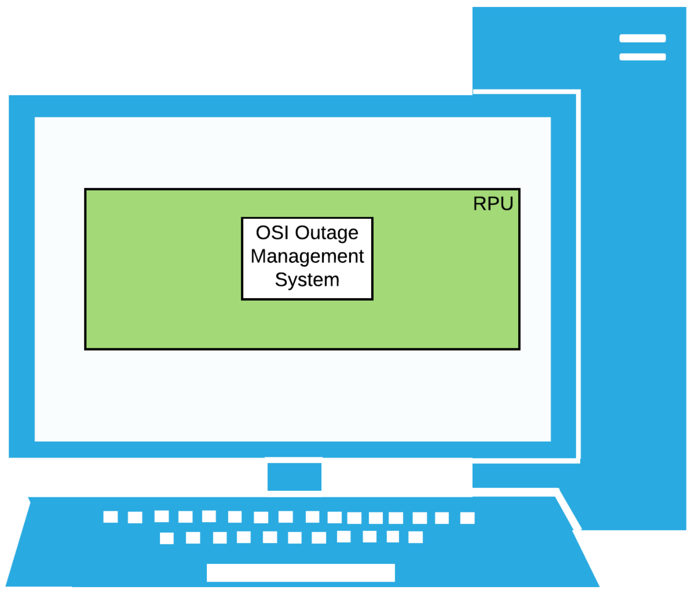
CleanStart DERMS
Approach

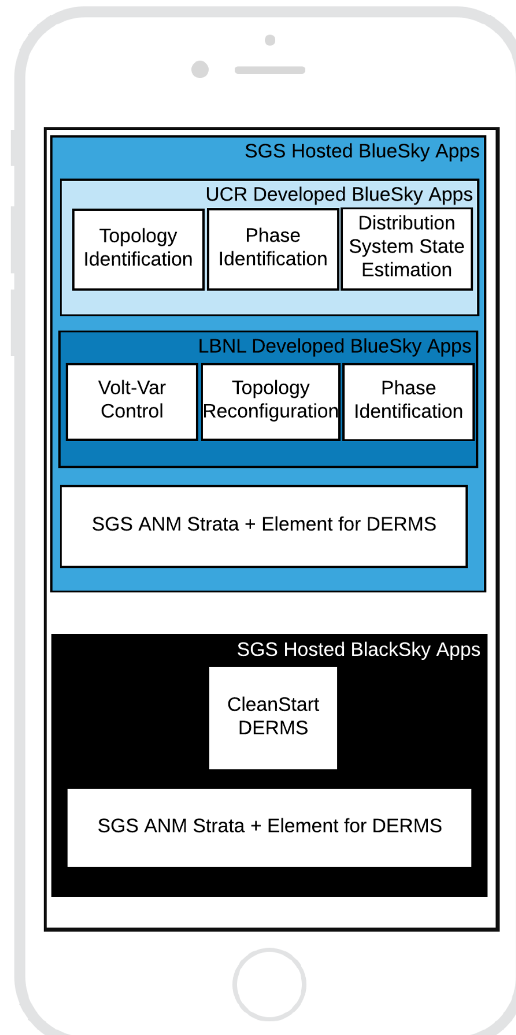
- Approach: Achieve black start and restoration objectives through combination and application of advanced co-simulation and architecture design, measurement and analytics, controls and optimization, communications and cyber security
- TD&C co-simulation planning tools will be used to design, validate and evaluate CSDERMS controls and scale up results for metrics and impact



- Distinctive characteristics
  - Development of dynamic ad-hoc microgrids, which form around resilience objectives integrating both traditional and non traditional DER
  - Solves critical problems for partner utilities yet applicable throughout the nation at similar facilities

Application Container/iPhone Analogy – Interlinkage between ENERGISE and CSDERMS





Progress – Year 1 Summary

- Subcontracting and scope for team
- Conceptual Design for Casa Freeman Area
- Use Case Development & Review with Utility Partner
- Modeling, Simulation Platform and Scenario Development
- Restoration Algorithm Testing in Simulation and with SGS (DERMS vendor implementing the solution)

- Challenges:
  - Utility framework for rapid demonstration of earlier stage concepts
- Success:
  - HIL demonstration plan approved and subcontracted
  - Use case documentation
  - Cyber and data security Plans Approved by Utility
  - Approval from utility for SGS equipment & sensors
  - Agreement form teams at UOC and EOC
  - Data collection and initial simulation plan

Progress – Year 2

- Sensor – Sentient and uPMU installed in test locations
- Recloser/Relay equipment installed
- Conceptual Design & Subcontract for Engineering Design & Costing
- Simulations in HELICS – control structure
- HIL testing with PG&E, SGS, One Cycle Control – for controls and use cases, finalize CONOPS & assessment plan
- Cyber Security – change to active scanning
- Design of 3 layers of control, control algorithms: tested in simulation & at SGS test lab
- Timeline Shift on Physical demo - RPU contracting and storage

Progress: Data Architecture & Sensor Installation

UPMU + Sentient Data

Dell Blade Server (or similar) – Hosting OSISoft local implementation (3 days data backup locally)

Local Analytics for Restoration
- Topology
- Resource Availability
- Stability & resilience of each node
- Ambient condition

RPU OMS/EMS PI Historian

OSISoft PI integration for long term analysis, visibility and storage

SGS DERMS & Restoration Algorithms

<u>Progress FY19:</u>
Sensors Installed, Data in Cloud, Resilient Data Node in progress

Progress: Restoration & Control Algorithms Summary

Restoration Optimization Algorithm (LANL)

Goal – What sections and generators should participate in each segments restoration & when

Device Controls – Collaborative Autonomy (LLNL)

Goal – verify that choice is correct, and advised, device layer communication and response

Device Controls - Stabilization and Feedback (PNNL)

Goal – individual device stabilization

Primary Use Cases

Optimization & CA Algorithm (CleanStart Op)

- Developed by Los Alamos Lab will calculate the best assets to facilitate the black start process and the closing sequence of the utility switches to rebuild the islanded system.

UC 1: Initial restoration of an islanded segment

- Explore variability in availability of DER assets and state of charge of BESS.
- UC 1 executed twice for energizing neighbouring microgrids

UC 2: Enlargement of the islanded segment with additional nodes

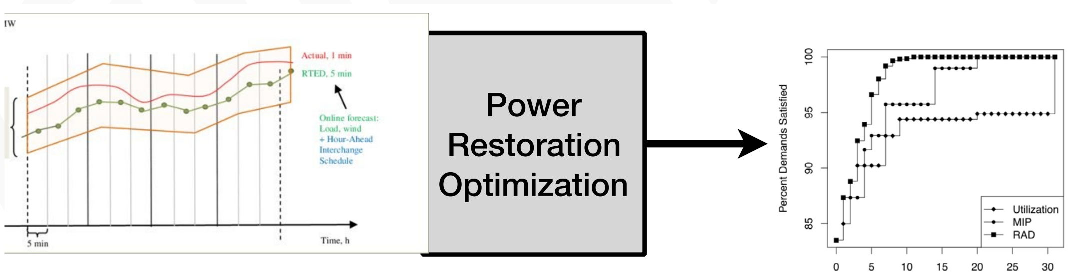
- Pick up of adjacent loads and PV
- Determine whether the algorithm needs to be re-run.

UC 3: Synchronizing and combining two islanded segments

- Frequency and phase are aligned across switch before closing connection

Layer 1 Restoration Optimization Algorithm: Key Questions

- Given available DER, what subset of the feeder can be re-energized?
  - Similar to designing and operating an ad-hoc microgrid
- Key Considerations
  - Operational Constraints (e.g. DER limits, phase balance, voltage levels, state of storage)
  - Reliability (e.g. N-1, renewable variability)
  - Load Priorities
- Determine a sequence of incremental restoration steps to get from the current state to the desired state
  - Objective, restore as much power as possible as quickly as possible.
  - Key action, which switches to close next?

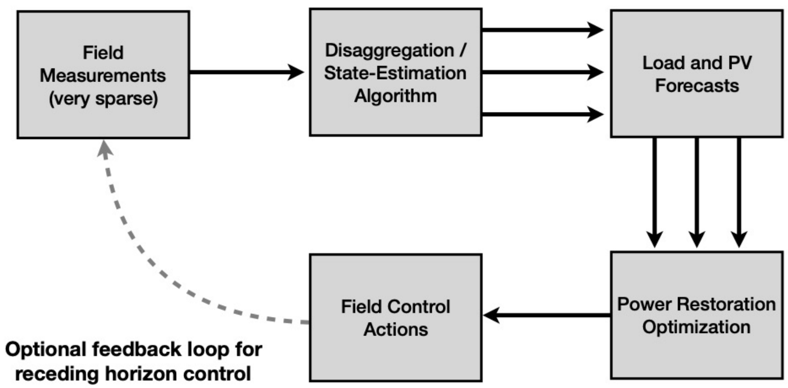


Restoration Algorithm Overview – Summary

- Restoration Timeline
  - 1 hour planning horizon
  - Restoration actions at 5 minute intervals
  - 12 restoration steps (for demo area)
- Inputs for Initialization
  - Network Assets (fixed OpenDSS model)
  - Load and PV forecast from local historian
  - Algorithm settings (e.g. initial state, CLPU factors, risk margins)
- Outputs
  - DER control actions for each restoration step
  - Switch settings for each restoration step

Progress

Implemented in SGS DERMS layer – tested in HELICS and SGS lab (July 2019) LANLYTICS API, script has been successfully deployed on a test system using ANM Pre-processor.



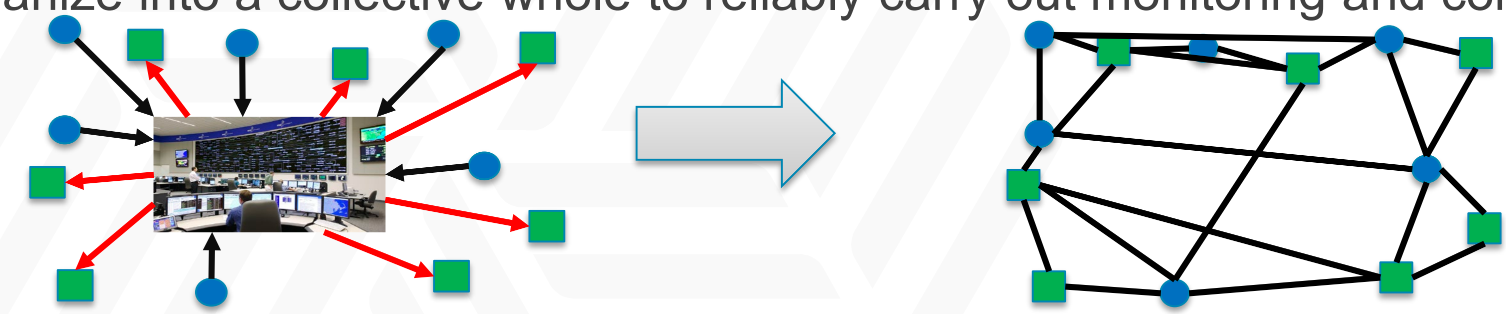
Core control loop

The LANLYTICS API is a generic distributed compute engine that allows arbitrary services to be executed via a HTTP interface.

Layer 2: Collaborative Autonomy Overview & Goals

- Restoration is based on the last best known, and a set of forecasting algorithms, after a prolonged (or even short) outage or event, the local knowledge may be inaccurate
- Utilize peer to peer measurements to verify the correctness of the command – provides both cyber and physical robustness

- A new class of computational techniques in which many devices can self-organize into a collective whole to reliably carry out monitoring and control



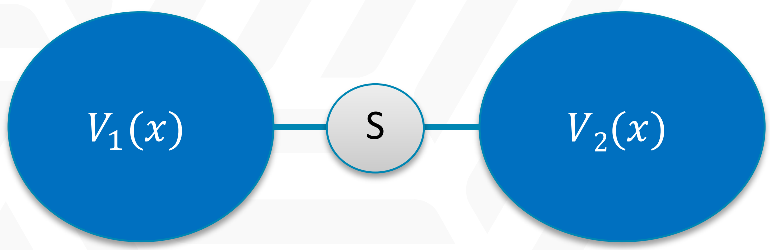
- ☐ Completely remove's the single point of failure of a centralized control center
- ☐ CA calculations are….
  - Decentralized, redundant, and ensure verifiable behavior
  - Fault tolerant => cyber resilient

CA Trust but Verify- Approach

Consensus Optimization CA Solution: Both islands need to collectively decide how to tune the phase angle parameters, x_i , so that the voltages, V_1 and V_2, are the same value.

Nonlinear Optimization Problem ⇨ ADMM (decentralized Optimization Solver)

ADMM: Find *x* to minimize: $V_1(x) - V_2(x)$

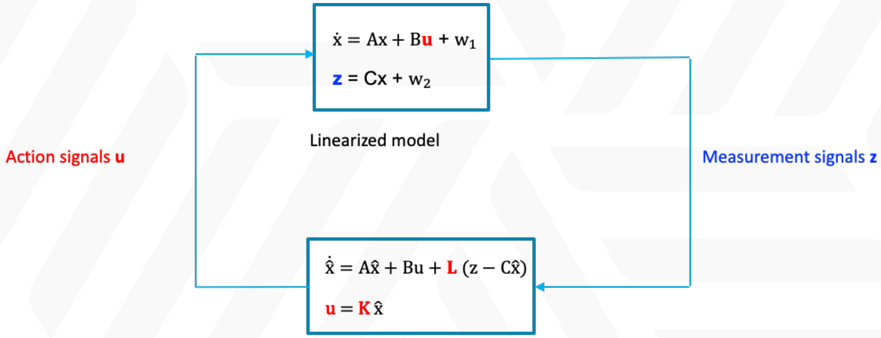


Each device…

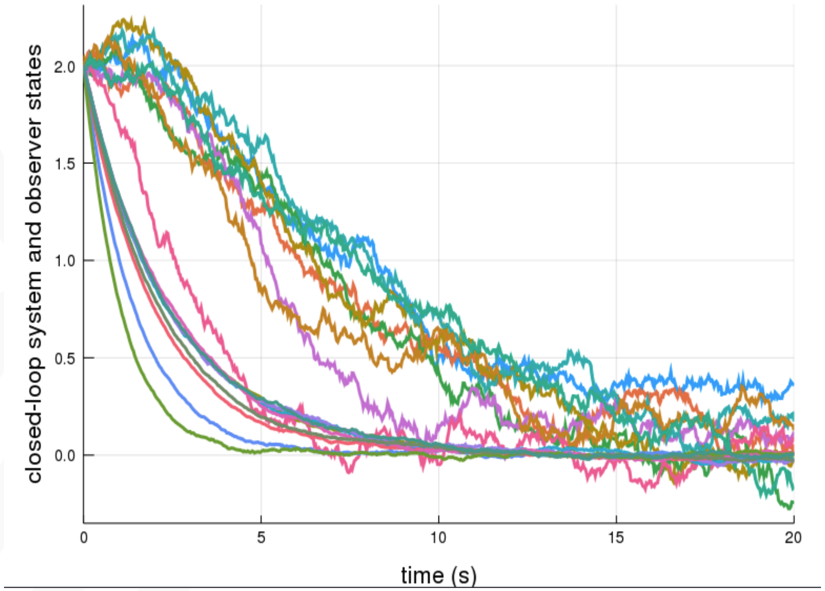
1. Applies its local update formula to guess at solution *x*
2. Sends its guess to neighbors, receives theirs.
3. If a neighbor's guess is too different, ignore it. Otherwise, incorporate it.
4. Repeat.

Layer 3: Device Stablization Layer

- Design the control to stabilize the energizing segment, given the linearized model with matrices A, B, C

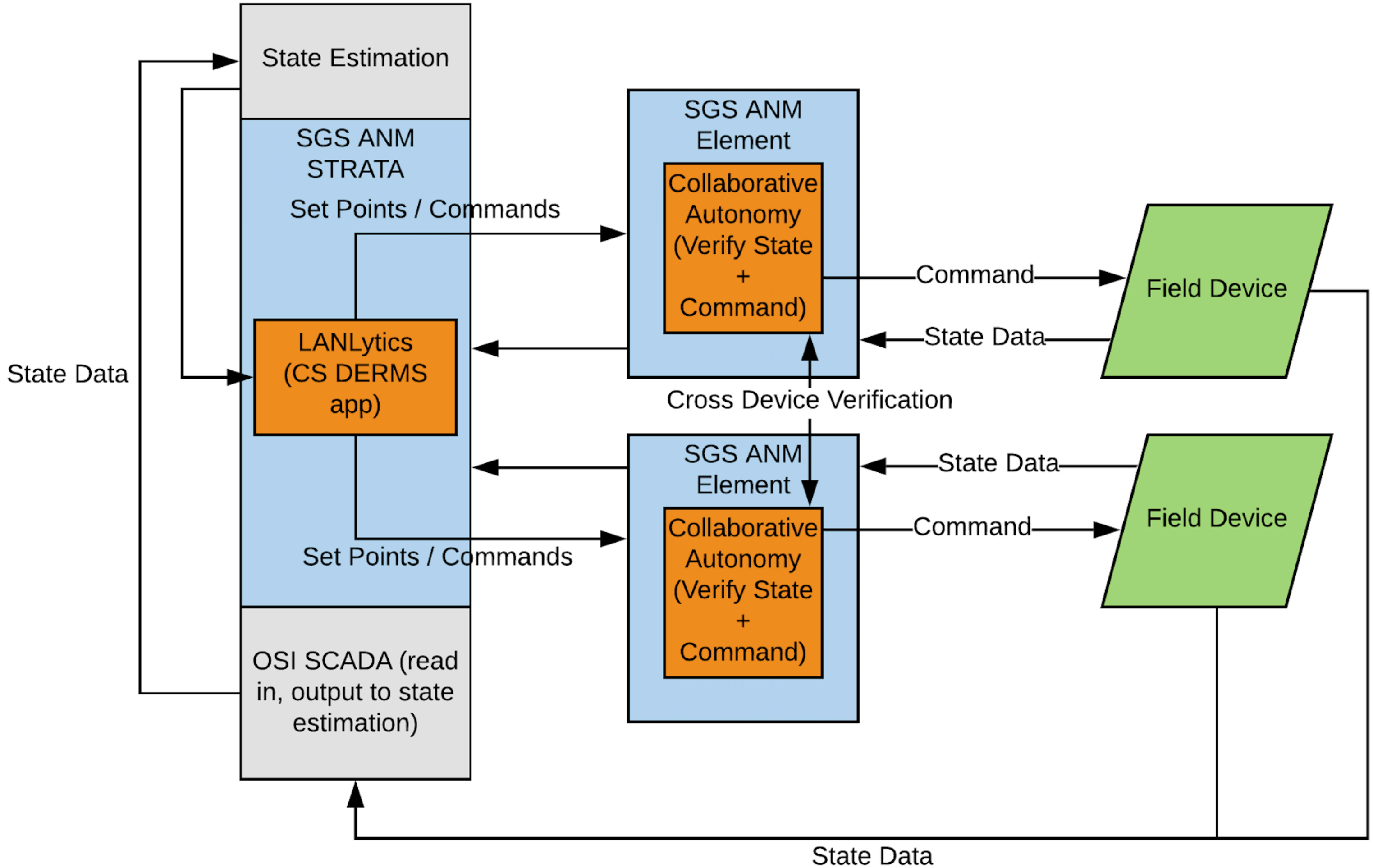


State-observer feedback Controller: K, L are obtained by solving convex optimization

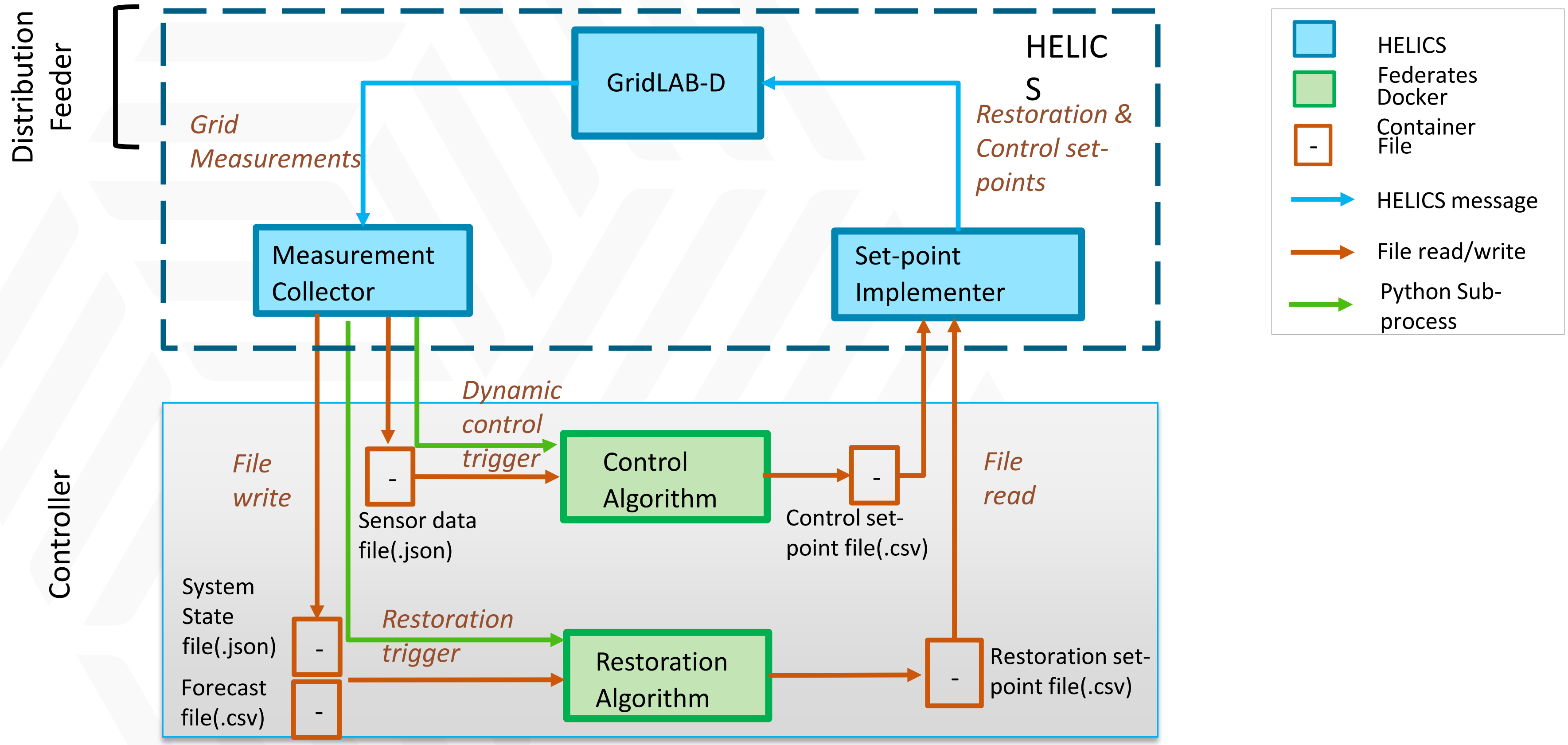


Stability of the system with measurement-feedback control. The smoother curves are the dynamics of the state estimates, while the noisier curves are the system states

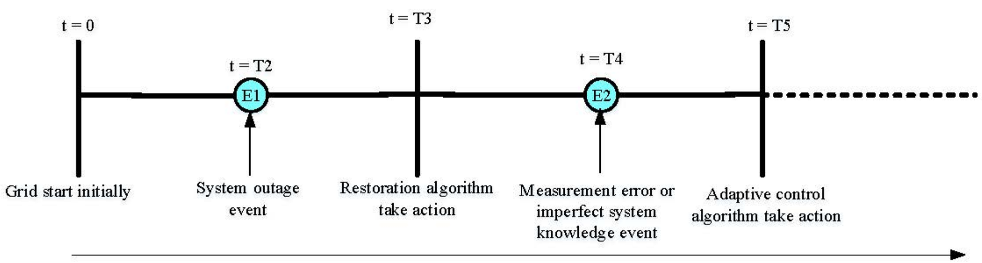
Control Deployment Architecture



Progress – HELICS Simulation Testbed



DERM Simulation Scenario Implementation



1. Incomplete scenario:
   a. Skip 25% of sensors data (one sensor out of the 4) to control algorithm.
   b. Open the four switches in the area of interest.
   c. Run the simulation and evaluate the results.
   d. Re-run the scenario with complete data.
   e. Compare the results from c and d.
2. Inaccurate scenario:
   a. Change the data by 10% on 25% of sensors data (one sensor out of the 4) to control algorithm.
   b. Open the four switches in the area of interest.
   c. Run the whole simulation and evaluate the results.
   d. Re-run the scenario without manipulation.
   e. Compare the results from c and d.

- Two initial scenarios under implementation: 1) Incomplete data; 2) Inaccurate data.
- Variations and anomalies are implemented in the measurement data and network.
- Current tests successfully showed that the control and optimization software executed for set timesteps even with minor anomalies.
- On-going simulations couple the above anomalies with events:
  - ☐ Switching events
  - ☐ Capacitor events
  - ☐ Loss of generation

Progress – Simulation Scenarios

<table>
<tr><td>22</td><td>Combination of several of the previous independent scenarios</td><td rowspan="3">Reliability, flexibility, security, sustainability</td></tr>
<tr><td>23</td><td>Unexpected behavior such as change in the weather leading to issues related to relying on PV; unexpected flow of EVs, etc. This scenario is in combination to some of the above scenarios that already resulted in loss of critical loads and other loads.</td></tr>
<tr><td>24</td><td>Loss of critical load surrounded by semi-stable neighborhoods:
• A critical load is tripped and OSS and CSS will be challenged to find the “ideal” path to restore power to the critical load.
• The critical load is in the area of interest. The feeder will be modeled as following: A portion of the area of interest is densely populated residential zone while the remaining portion of the area of interest is not as dense but has a commercial/industrial load with heavy amount of Induction motors + VFD and other loads that may need high start-up current.
• Taking the path of residential zone to the critical load may not result in high start-up current therefore, minimum risk and impact on the grid but due to net load consumption, the critical load may be powered for 30% less time than through the other feeder (the one with commercial/industrial load)
• Taking the path of commercial/industrial load zone to the critical load may result in high start-up current therefore, high risk and impact on the grid. So, the critical load may be powered for 30% more time than through the other feeder (the one with residential loads)
• This can be further expanded to add more events to it. The goal of this scenario is to test the ability of OSS and CSS to decide to power critical loads</td></tr>
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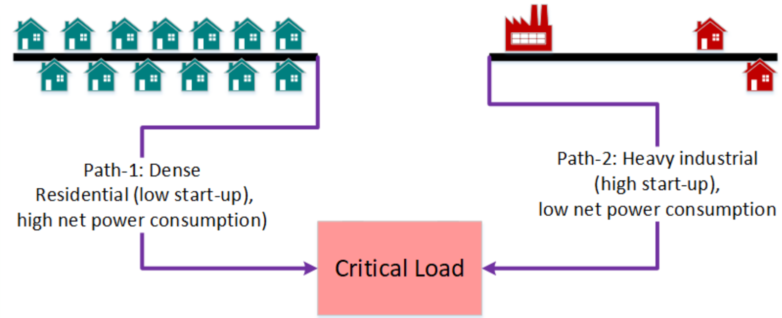
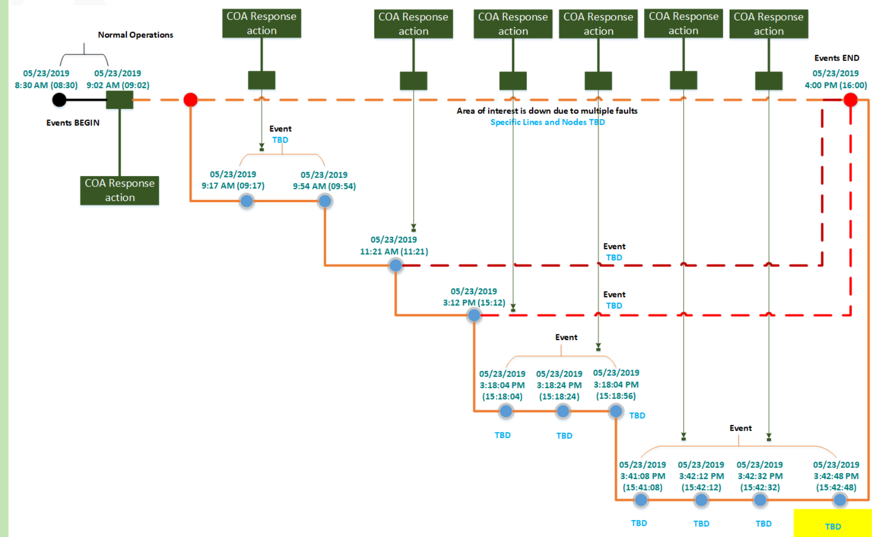
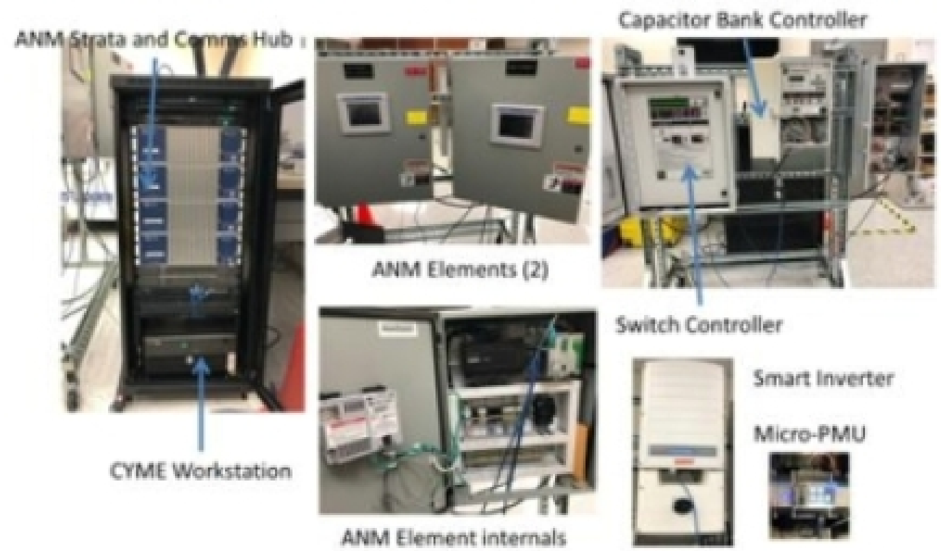




Progress: Hardware-in-the-Loop Equipment

- Building on setup for ENERGISE work with UCR and RPU
- Cyme is being replaced with RTDS because of nature of experiment
- Hardware being added to replicate the SEL Synchrocheck relay in the middle of the two ”islands”
- Schedule for test in December/January - FAT with RPU

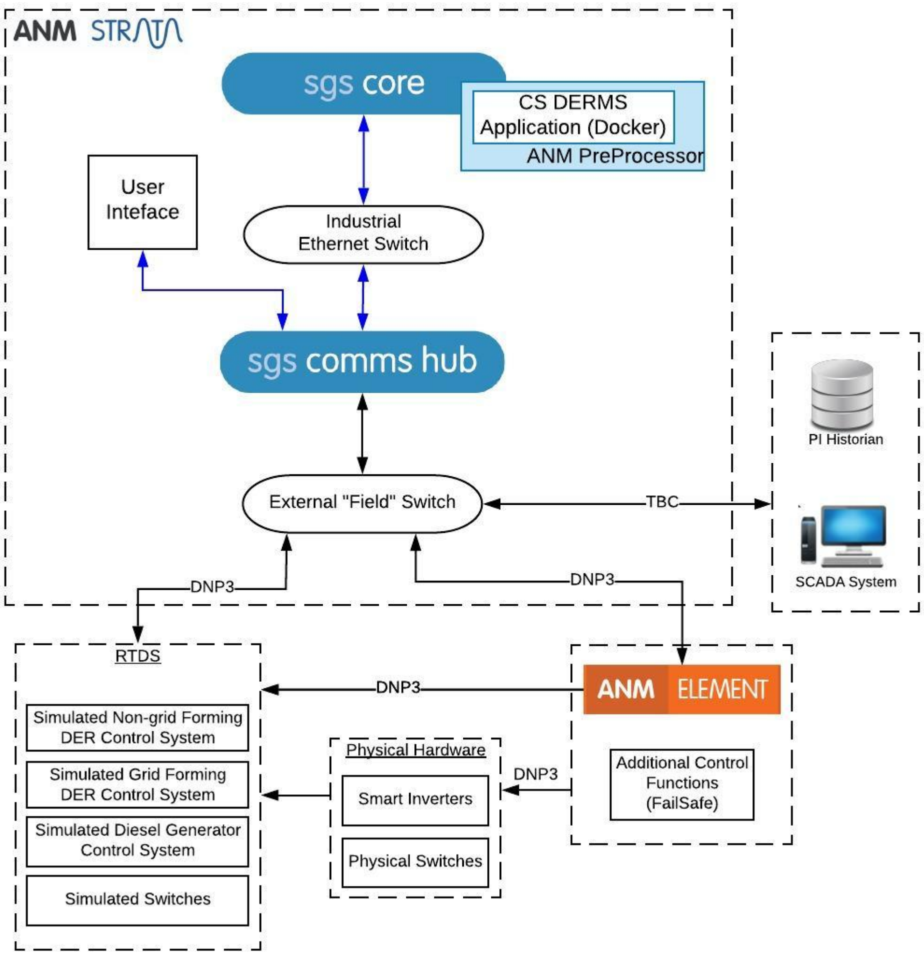


General ANM Requirements to be verified in HIL

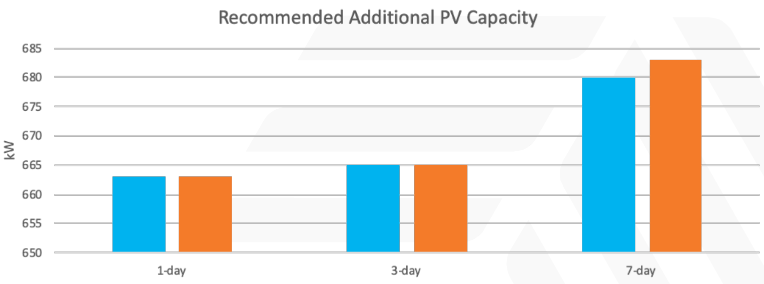
- **Fail to safe in the event of communications failure between DERs and the central controller.** In the case of failure of communications between a DER and the central controller, local control at the DER by **ANM Element** will adjust the output of the DER to a pre-defined level or move into a pre-defined control state.
- **Fail to safe in the event of communications failures**. The ANM system will be designed and implemented to fail to a customer defined safe operating state when communication failures are experienced.
- **Management of DER for non-compliance**. In the case of DER non-compliance to a setpoint issued by the ANM system, the ANM system will attempt to unload the DER (reduce output to a pre-defined level). If the DER fails to respond to the command to reduce output after a defined period, the ANM system will take preconfigured failsafe action.
- **Operational Data Store** to enable historical archiving of key operational data
- ~~**SSP-21 wrapper** integrated into the architecture and extended to SCADA to form a secure wrapping around the platform, which is enabled on reconnection of SCADA~~
- **Active Scanning-** and integration of comms modeling (see later slides)

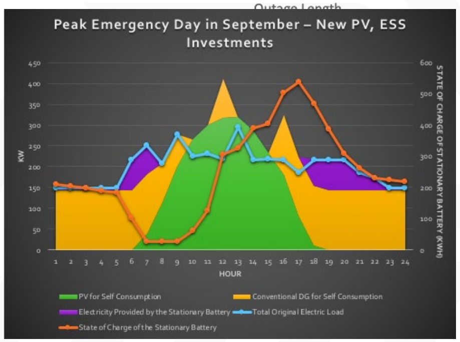
ANM Strata Platform Configuration (in HIL)

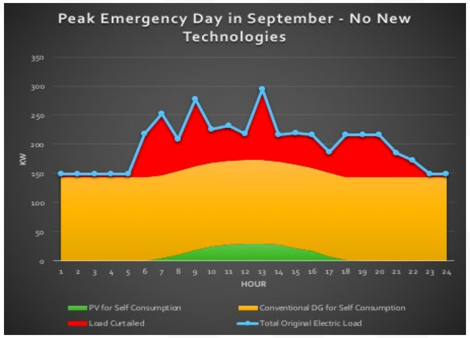
- Hardware-in-the-loop (HIL) architecture, featuring ANM Strata (core & comms hub) and ANM Element
- CleanStart Op algorithm is hosted as a Docker container ANM Strata (called by ANM PreProcessor application)
- CA will be tested on 2 to 3 Elements
- Progress: Scheduled/Subcontracted at PG&E ATS lab for Dec/Jan



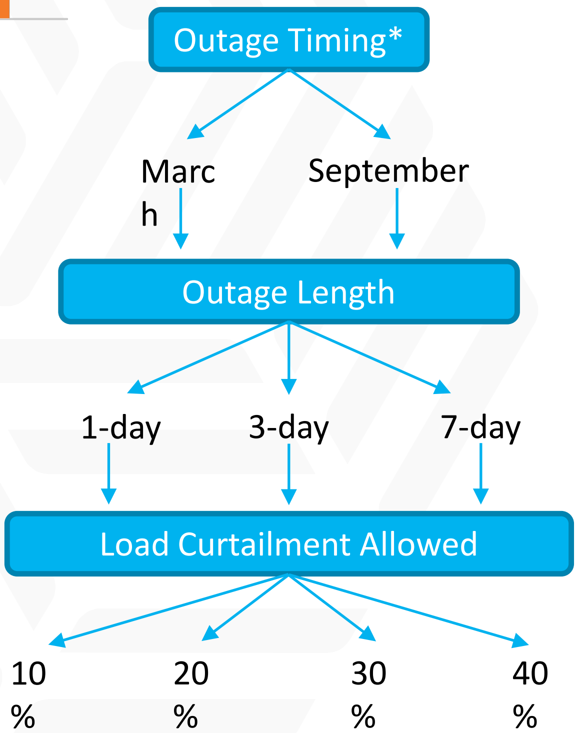
Scenarios
Sizing for EOC + UOC + Controllable Load Locations







*Note on Outage Timing: Each case models a single outage event, either in March or in September.

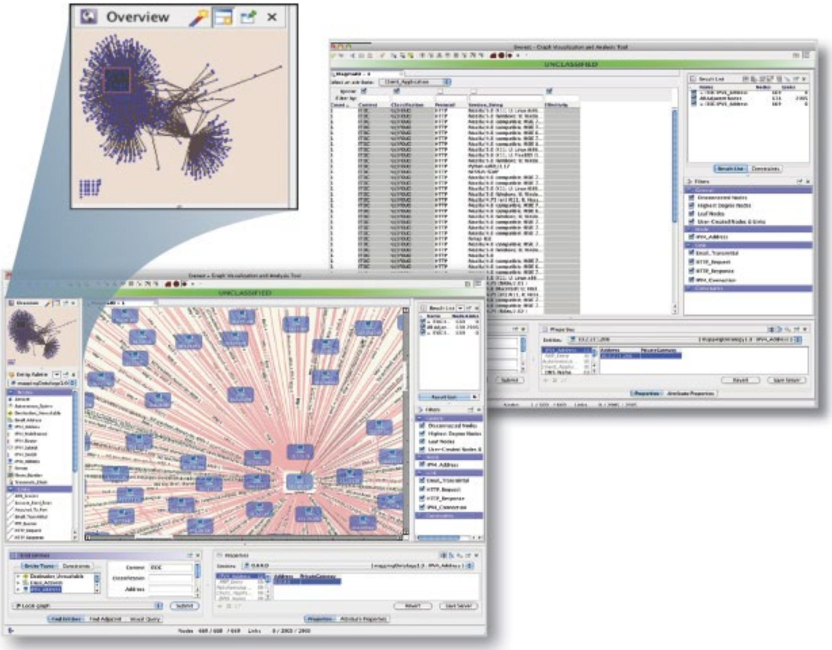


Total Number of Cases	24
Existing Technologies Modeled	UOC Generator, 275 kW
	EOC Generator, 500 kW
	PV, 150 kW
New Technology Forced	Electric Stationary Storage, 850 kWh
New Technologies Considered	Diesel Generator, 130 kW
	PV
	Hydrogen Fuel Cell, 100 kW
	Hydrogen Fuel Cell, 250 kW

Proposed New Path: Network Mapping System (NeMS) Deployment

- Understanding the components, structure, and activities of a computer network is the first step in many cyber defense and cyber mission assurance operations.
- NeMS is a software-based network characterization and discovery tool that produces a comprehensive representation of IP-based computer network environments.
- **Benefit: identify existing communications architecture weaknesses and vulnerability, continuously monitor for both power and cyber**

Lawrence Livermore National Laboratory



Milestones – 1 Complete/Near Complete

Milestone Name/Description	End Date	Notes
Project Q1 Progress Measure: **Task 1.1 – Data collected from existing network of uPMU, SCADA, AMR & shark sensors for the preceding year and input to data collection platform to be shared amongst the project team**	12/31/18	Broken modem replacement in progress for uPMU Sentient Sensors in place SCADA & AMR delivered Models Delivered
Project Q2 Progress Measure: **Task 1.6 – Draft cyber security and data plan is delivered & approved by stakeholders**	3/31/18	Complete and Approved – see network scanning follow on
Project Q3 Progress Measure: **Task 1.2: Calibration and model validation complete, showing 95% accuracy against measured and modeled data for the existing system state.**	6/30/18	Complete
Project Q4 Progress Measure: **Task 1.8: Utility & Restoration teams approves use case for blackstart & cleanstart DERMS at workshop**	9/30/18	Complete – on site workshop in Feb 2019
Project Q5 Progress Measure **Task 2.1: Finalized HELICS simulation of scenarios complete, and validation of controls in simulation is approved by utility demo partner and adequate to provide a restoration pathway in the selected scenarios for outage**	3/31/19 Update to 8/31/19	HELICS Simulations in progress – data collection and contracting delay – see progress report No delay to HIL Controls are in place now

Milestones

Milestone Name/Description	End Date	Note
Project Q6 Progress Measure **Task 2.3: Initial selection of technology vendors for DER and subcontracting in place**	3/31/19 – Subcontracting 9/31/19	Subcontracting delay – OCC in progress for inverters, Sentient complete, SGS complete, PingThings Complete, Storage going through RFP process
Project Q7 progress measure **Task 2.4: Utility approves robust communication of selected devices with automation and communications laboratory within operations center, operations staff approve utilization in outage scenarios for demonstration at RPU/ EOC UOC**	6/30/19 – subcontracting delay 10/15/19	Not critical path – but in progress with PingThings on point
Project Q8 progress measure **Task 2.5: SSP-21 is tested in situ with SGS platform, against red teaming and is considered viable and secure to utility protocol – change to task based on CEDS change in focus Replace with active scanning…**	**9/30/19 – 12/30/19**	**See description of change**

Milestones

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Milestone Name/Description	End Date	Note
Project Q9 progress measure **Task 2.6: Functional acceptance testing in HIL is complete and utility approval in place**	12/31/19	On track – subcontracting and test plan in place
Project Q10 progress measure **Task 3.2: Equipment installed on site and in operation, including storage truck, new inverters**	6/30/20	**likely + 3 - 6 months with subcontracting & RFP Process**
Project Q11 progress measure **Task 3.3: Full validation and testing complete of 2 building restoration**	6/30/20	**likely + 3 - 6 months with subcontracting & RFP Process**
Project Q12 progress measure **Task 3.5: Presentation of results at large workshop (Distributech)**	***9/30/20***	***Move to DTECH 2021 – suggestion of booth for RDS project***