GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.5.02 – Resilient Alaskan Distribution system Improvements using Automation, Network analysis, Control, and Energy storage (RADIANCE)

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Washington DC

RADIANCE – Scope and Budget

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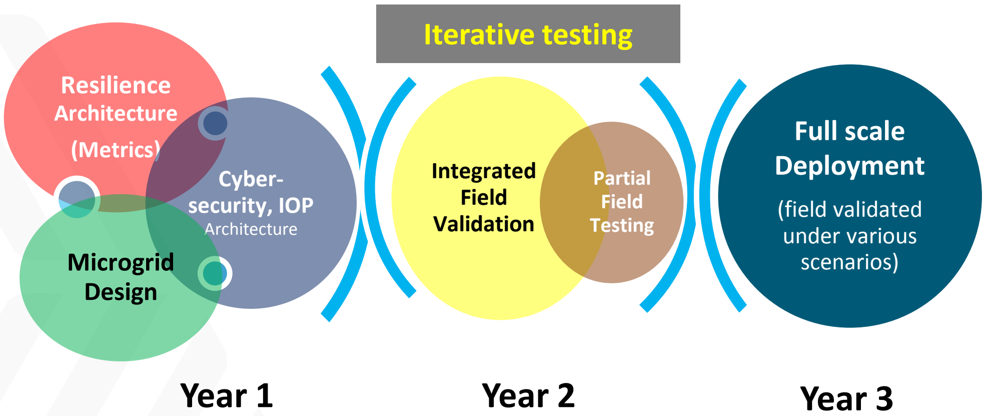
Objectives & Outcomes

- Regional field validation of resilience enhancement methods for distribution grids under harsh weather, cyber-threats, dynamic grid conditions using multiple networked microgrids, energy storage, early-stage grid technologies such as distribution-PMUs
- Iterative HIL testing, results from partial field deployment, leading to field validation, and leveraging GMLC 1.3.9 project to minimize deployment risk of modern power and cyber technologies, develop insights for practical use of metrics from GMLC 1.1 and new resilience metrics from this project
- **Resilience by design** – using **zonal approach** in **multiple loosely- and tightly-networked microgrids**
- **Lessons learned and roadmap** to develop networked microgrids as a resiliency resource in distribution grids



Technical Scope

1. **Resilience Metrics Framework for Design and Operation –** Develop and demonstrate practical use **of resilience metrics** for coordinated operation, design to minimize outages, financial losses
2. **Multiple Networked Microgrids in Distribution System – Leverage rotational** and virtual inertia of microgrids assets including **hydro**, diesel, energy storage, and **micro PMU-based sensing** to enhance resilience of the overall regional distribution network
3. **Cyber-security Architecture and Rapid Prototyping of Controls –** Rapid prototyping of controllers as HIL and cyber-vulnerability testing in a **real-time cyber-secure environment**
4. **Field Validation of Resiliency Enhancement Methods – Field validation of increasing resiliency** of the overall distribution system by leveraging resources from **multiple networked microgrids**

Life-cycle Funding Summary ($K)

FY17 & prior, authorized	FY18, authorized	FY19, authorized	FY20 authorized
0	2,270	2,340	1,620

PROJECT FUNDING

Lab	Year-1	Year-2	Year-3
INL/NREL	$450K	$500K	$550K
SNL	$300K	$300K	$350K
PNNL	$250K	$200K	$200K
Cost Share	$300K	$1070K	$200K

Goals and Objectives

- **Cultivate a better fundamental understanding of resiliency in purview of multiple tightly- and loosely-networked microgrids**
  - Develop a **systematic framework for quantification**, and **practical application** of resilience metrics/methods
  - Identification and incorporation of **unique**, **multi-dimensional**, **physical** and **cybersecurity** aspects of microgrids and distribution grid in **resilience metrics**
  - Application for ***resilience-by-design*** and **real-time** opera
- **Regional field validation of resilience enhancement for distribution grids under harsh weather, cyber-threats, and dynamic grid conditions**
  - **Coordinated operation** of **multiple networked microgri** with **high penetration of clean** and heterogeneous DERs enhanced resilience
  - **Micro-PMU** – an **early-stage grid sensing technology** fo real-time controls
  - **De-risking field deployment by iterative HIL testing and validation**
  - **Robust cyber-secure communication** to mitigate cyber-attacks
  - **Evaluation of storage** technologies to harness community level solar, ***hydro storage (planned),*** and wind (profiled)

Demonstration Site – City of Cordova, AK

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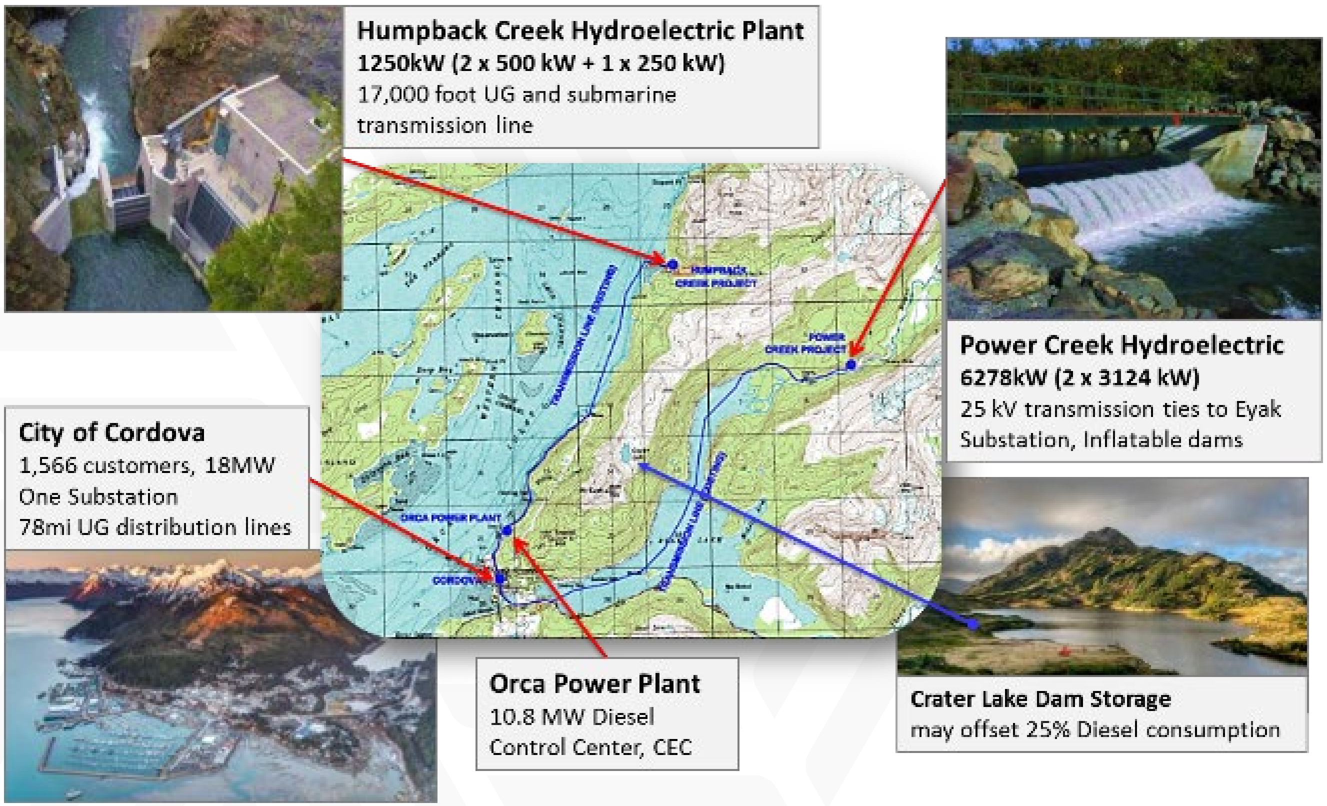

- 1MW/0.97MWh ABB-Saft BESS installed and commissioned in August 2019
- A new fiber optic network has been installed and commissioned between all generating stations and Eyak substation
- Advanced Metering Infrastructure and dispatchable electric boiler to be installed and commissioned in FY20
- Sensors for precise flow measurement at PowerCreek Hydro – in design process (to be commissioned in FY20)

Project Team

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NREL Transforming ENERGY | INL Idaho National Laboratory | Sandia National Laboratories | Pacific Northwest NATIONAL LABORATORY

Digital Real-time Simulation, HIL, Rapid prototyping, cyber-vulnerability and security analysis testbed, virtual rotational inertia controls, batteries	Microgrid design (MDT – Microgrid Design Toolkit) and control testbed, PHIL Inverter testbed, Stability, energy storage, protection systems, field deployment	Micro-PMUs and sensor placement t, fault propagation, communication networks testbed and protocols, IEC61850, IEC 62351, GridLab-D integration

City of Cordova ALASKA — Demonstration site, Engineering and deployment

AVEC ALASKA VILLAGE ELECTRIC COOPERATIVE — 58 remote village communities in AK

SIEMENS — Energy Storage Management System

MICROGRID DESIGN TOOLKIT — Microgrid design, controls vendor for networked architecture, protection

NRECA America's Electric Cooperatives — Rural electrification leadership, outreach

ACEP Alaska Center for Energy and Power — University partner, rural microgrid research, microgrid and communication design, field deployment, utility interaction

CEC — Utility partner, engineering support, field deployment

WASHINGTON STATE UNIVERSITY — Resilience metrics, valuation analysis, baseline

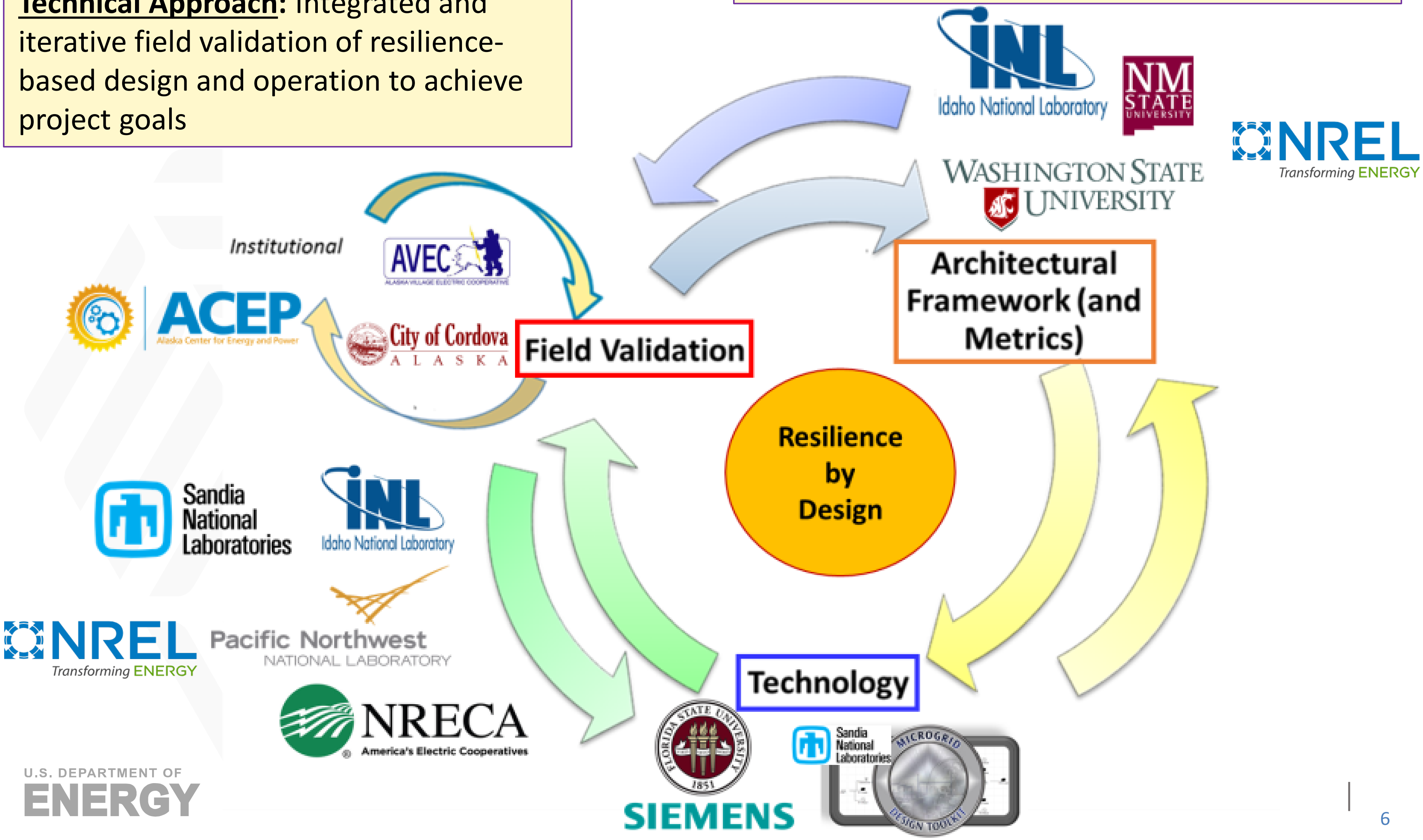
NM STATE UNIVERSITY — Microgrid design, stability analysis

CLEMSON UNIVERSITY — Protection design and testing

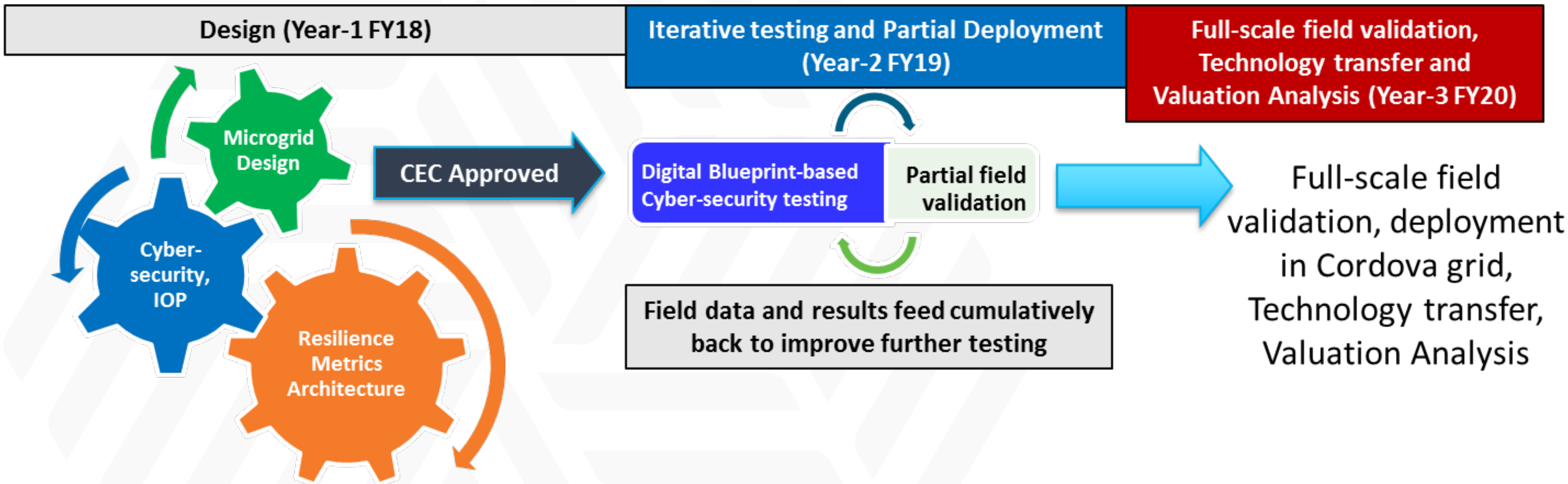
Approach

Lab Valuation Analysis Team: Led by Pete Larsen (LBL)

Technical Approach: Integrated and iterative field validation of resilience-based design and operation to achieve project goals



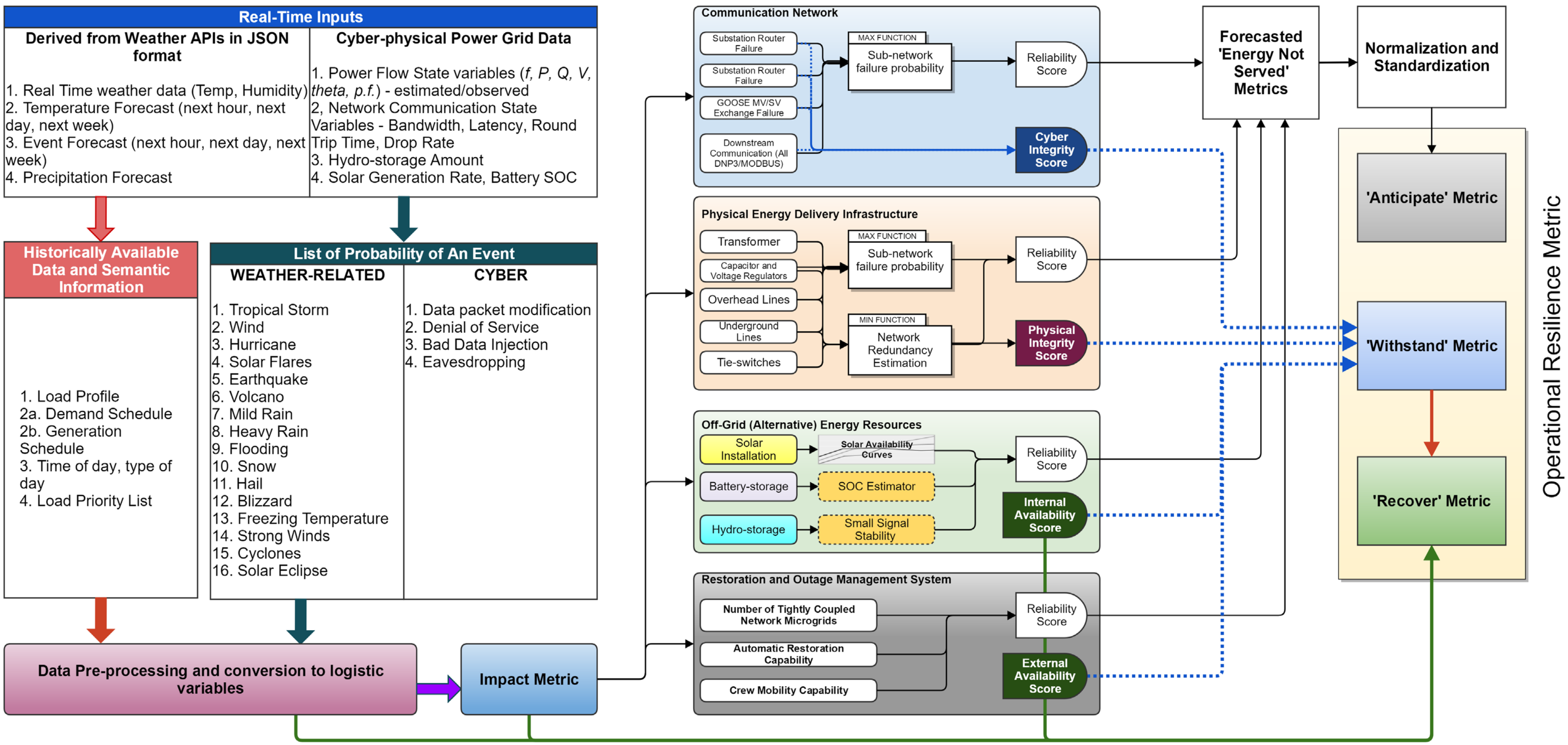
Approach


Design (Year-1 FY18)
Iterative testing and Partial Deployment (Year-2 FY19)
Full-scale field validation, Technology transfer and Valuation Analysis (Year-3 FY20)
Microgrid Design
Cyber-security, IOP
Resilience Metrics Architecture
CEC Approved
Digital Blueprint-based Cyber-security testing
Partial field validation
Field data and results feed cumulatively back to improve further testing
Full-scale field validation, deployment in Cordova grid, Technology transfer, Valuation Analysis

- In current phase of the project, three Integrated Project Teams (IPT) are focusing on
  - **Cybersecurity Plan IPT**
    - To include cyber and network information before RADIANCE.
    - To develop plans and policies for cyber-secure communication and access of the existing system, and future upgrades/additions of hardware and software.
  - **Microgrid Control Design IPT**
    - Selection of microgrid vendor based on requirements – choice selection matrix.
    - Identification of local critical loads, layout and profiles for developing requirements.
    - Utilize Sandia's MDT for specifying microgrid control design including physical aspects and cyber-threat scenarios.
  - **Baseline of Cordova Distribution System IPT**
    - To establish a baseline system and quantify the baseline performance using metrics framework in line with LVAT.
    - Utilize system survey and field measurements/data from PMUs, SCADA to develop baseline performance for comparison at the end of the project.
  - **Testing IPT**
    - Coordinate development of the digital twin (digital blueprint) of CEC system in DRTS.
    - Coordinate of unit testing with each IPT.
    - Integration testing in field.

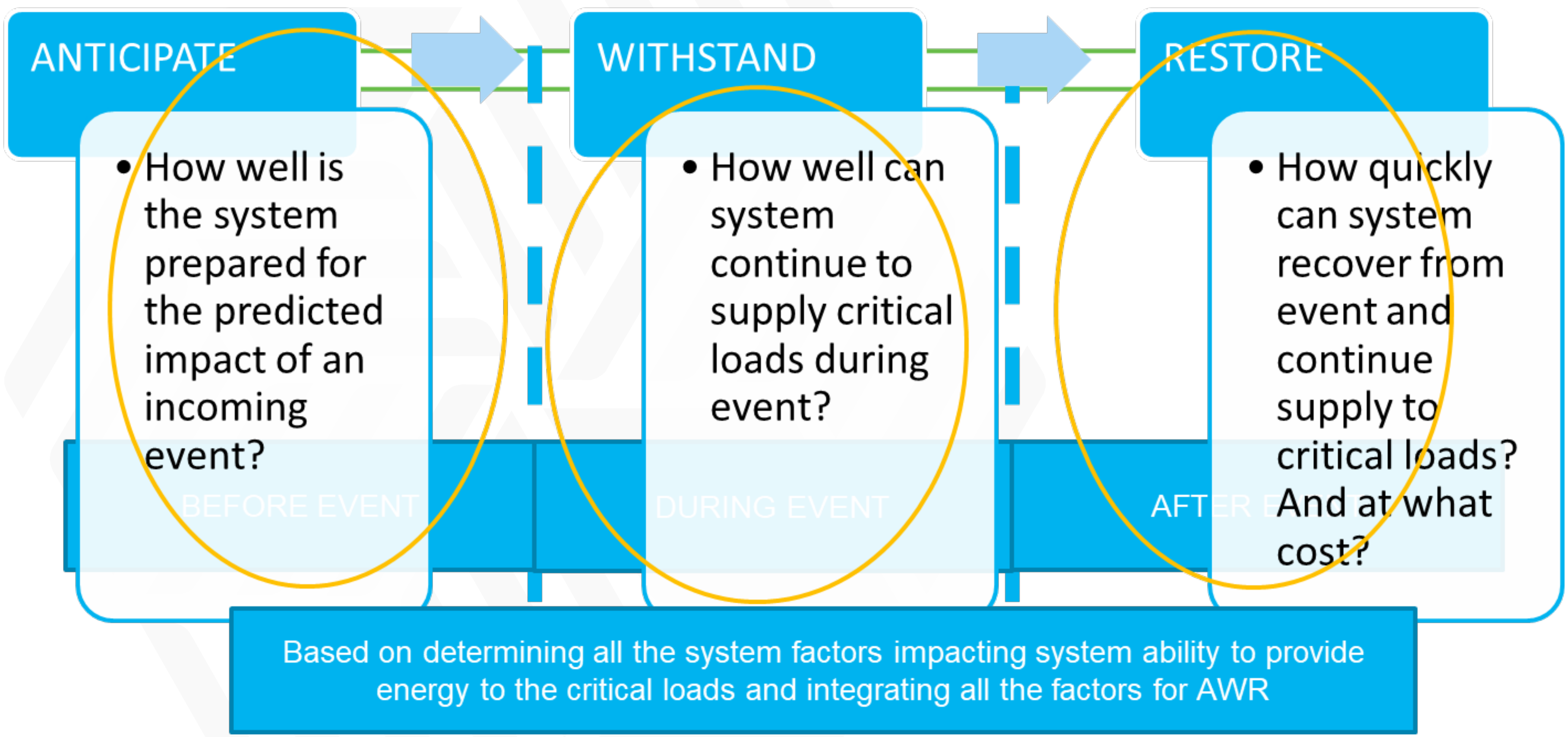
Approach – Resilience by Design

- Operational Resilience Metrics Computation Flowchart

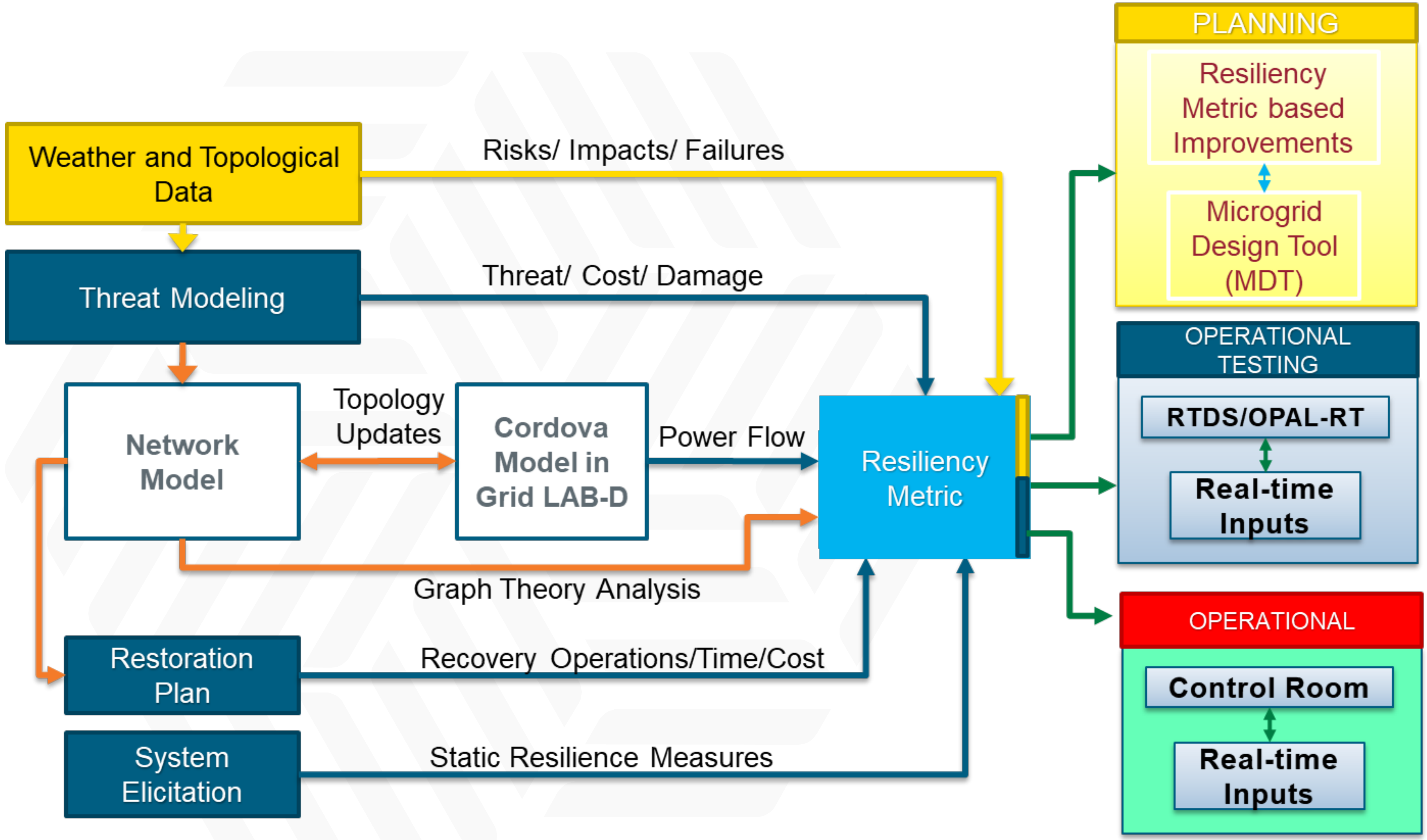


Approach - Resilience Metrics Definition

Multi-temporal Multidimensional Resilience Framework



Approach - Resilience Implementation Framework Overview



Baseline IPT – Progress and Status

- Analysis of “Blue Sky” scenario.
- Provide historical data from prior threats, such as tsunamis, earthquakes, and extreme weather.
- Existing system SCADA data management.
  - Automate collection and monitoring of SCADA data.
    - Establish a database for historical data in a Canary Lab environment for RADIANCE project.
  - Define historical dynamic events and provide associated data to RADIANCE team members for modeling and validation.
- Year-3 task: Support deployment and field validation.

Baseline IPT – Progress and Status

- ► Analyze historical outage data using complex systems analysis tools.
  - ☐ Preliminary analysis complete. Behavior is isolated microgrid shows similar behavior to that of large national grid.
  - ☐ Master's student completed her thesis on this and will publish it in a technical journal.
- ► Determine which events are correlated with outages.
  - ☐ Analysis complete. Outages have not correlated with weather events since the transmission lines were buried.
  - ☐ Outages correlate with seasonal load.
- ► Define risk metric against which future changes to the grid may be measured, i.e.,
  - ☐ Risk metric has been defined.
  - ☐ Next step is to test.

Baseline IPT – Data Model Overview

Represent the flow of messages/data between different aspects of the system
- Scenario-dependent traffic
- Specific data dependencies between entities
- Frequency of updates/data transfer rates

Utilize the model to determine communication requirements and feasible boundaries for hardware and software representations in the digital twin

Utilize the model to determine where communication paths will need to be maintained in operations, and where alternatives may be useful

Utilize the model to determine important data for archiving

Baseline IPT – Data Model Progress & Next Steps

Current Progress

- Refining initial models of data flow under scenarios (baseline, avalanche, tsunami)
- Working with Cordova Electric (CEC) and Electric Power Systems (EPS) to improve the representation
  - Model the paths/data of the interactions accurately
  - Incorporate proper names/terminology

Next Steps

- Incorporate ESOT, microgrid controller, and uPMU details into the data flow
- Incorporate additional data characteristics (data rate, storage rates, data criticality)

Baseline IPT – Data Model Overview

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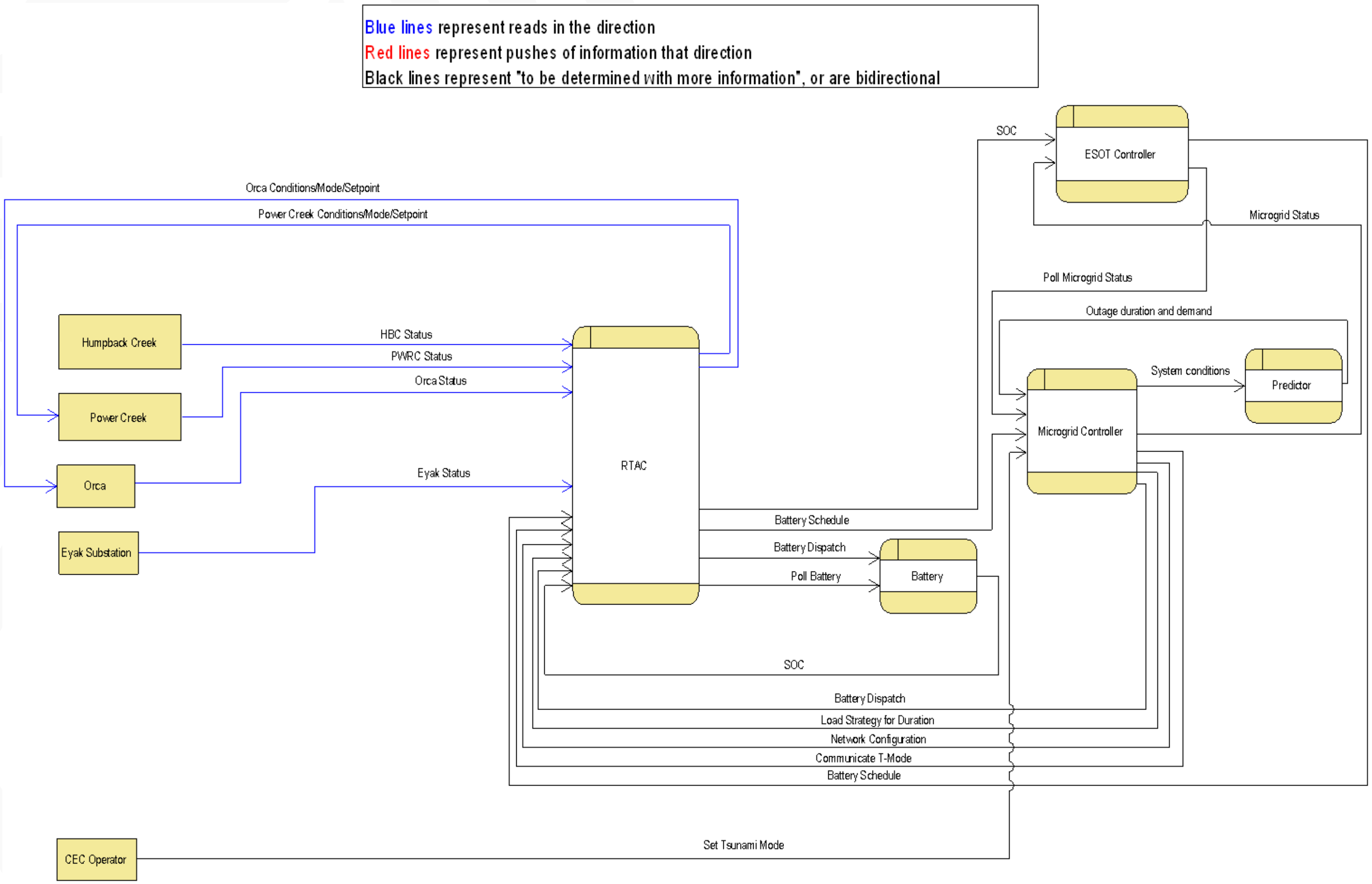
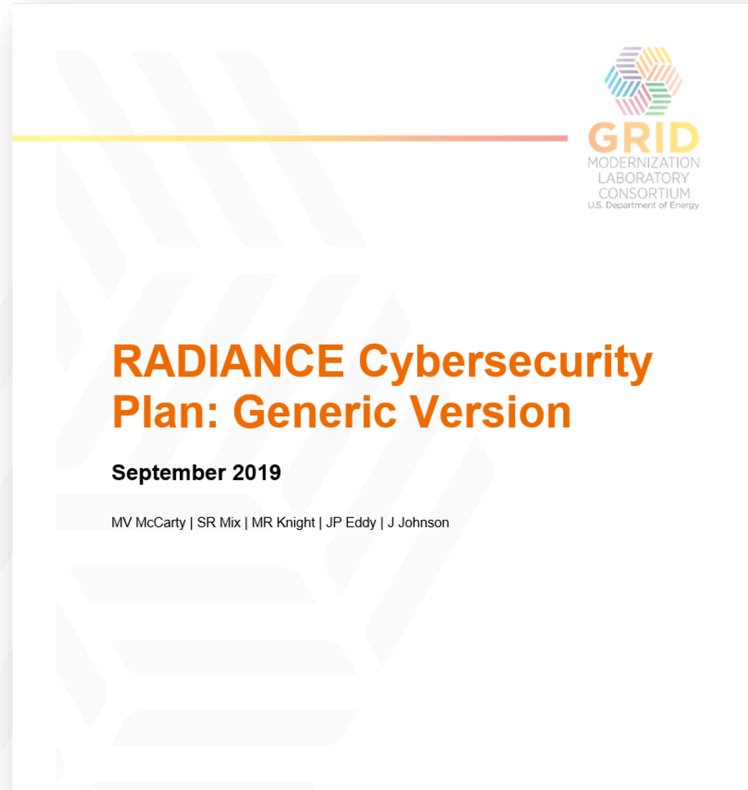
► Example – Simplified Tsunami Representation



Cyber IPT – Progress and Status

- Completed CEC Cybersecurity Plan
- Completed Generic Cybersecurity Plan
- Cyber Vulnerabilities and Mitigations Related to Communication Protocols Found in Energy Delivery Systems (Task 4.4 deliverable).
- Document in final review and release process at PNNL.
- Started deployment of SDN Equipment in CEC for increased security from Internet-launched attacks on VPN access.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RADIANCE Cybersecurity Plan: Generic Version

September 2019

MV McCarty | SR Mix | MR Knight | JP Eddy | J Johnson

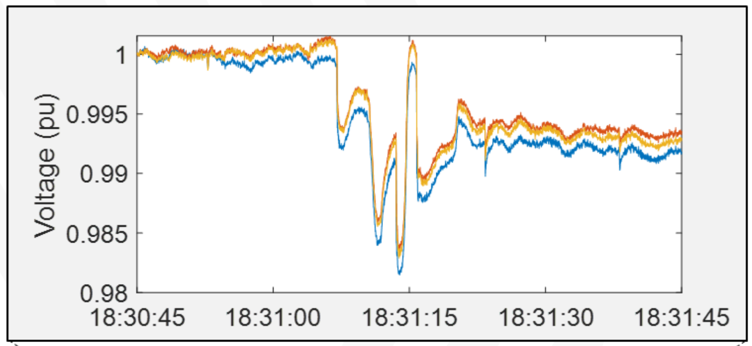
Cyber IPT – Progress and Status

► Micro-PMUs and PMU-based Event Detection

Cordova Electric Grid

- 4 PMUs installed

PMU Data



Archive Walker software

- Developed in GMLC 0072
- PMU-based event detection

Event Database

- Over 2 months of data analyzed
- Over 200 events detected

Digital blueprint validation at

- Sandia
- PNNL
- NREL
- INL

Model Validation

Cyber IPT – Progress and Status
Cyber-Physical Testbed Overview

- Represents integrated architecture of emulation, simulation and, Hardware-in-the-Loop (HIL)

- Purpose - To examine the cybersecurity of the Cordova microgrid, including:
- Analysis of cyber vulnerabilities of communication protocols
- Interoperability testing
- Identifying mitigation measures

- Focus is to identify cybersecurity vulnerabilities related to communication protocols and aspects such as communication latency

- Mitigation measures will be based on resilience metrics

Cyber IPT – Progress and Status
Cyber-Physical Testbed

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► Current Progress

- Updated the model in OPAL-RT simulator to match the latest PSLF model
  - Topology
  - Functional Mock-up Unit (FMU) for DEGOV1
  - RT-LAB model expanded (more controls, and feedback loops)
- Added simulated uPMUs at each substation
- Included DNP3 and Modbus communication blocks

► Next Steps

- Build I/O blocks and interface the simulator with the Relay and/or RTU
- Add the IEC 61850 communication blocks
- Finalize the Tsunami scenario and conduct the communication protocols vulnerability assessment
- Build and integrate the SCADA displays

Cyber IPT – Progress and Status
OPC Server (SCADA) & OpenPDC

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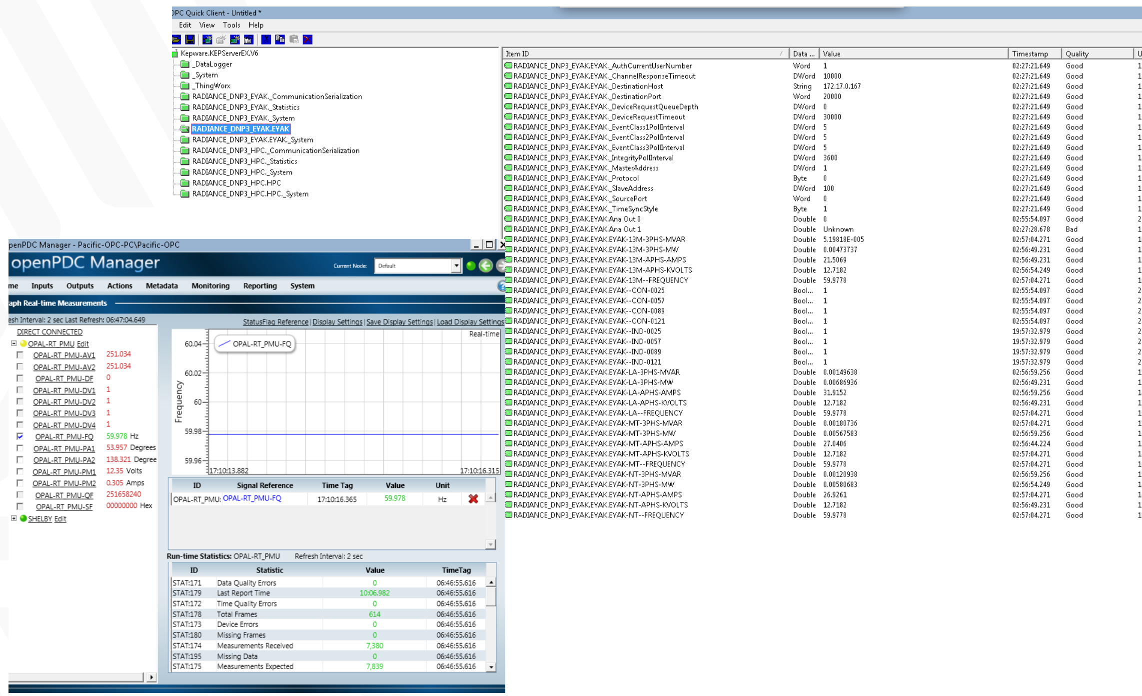
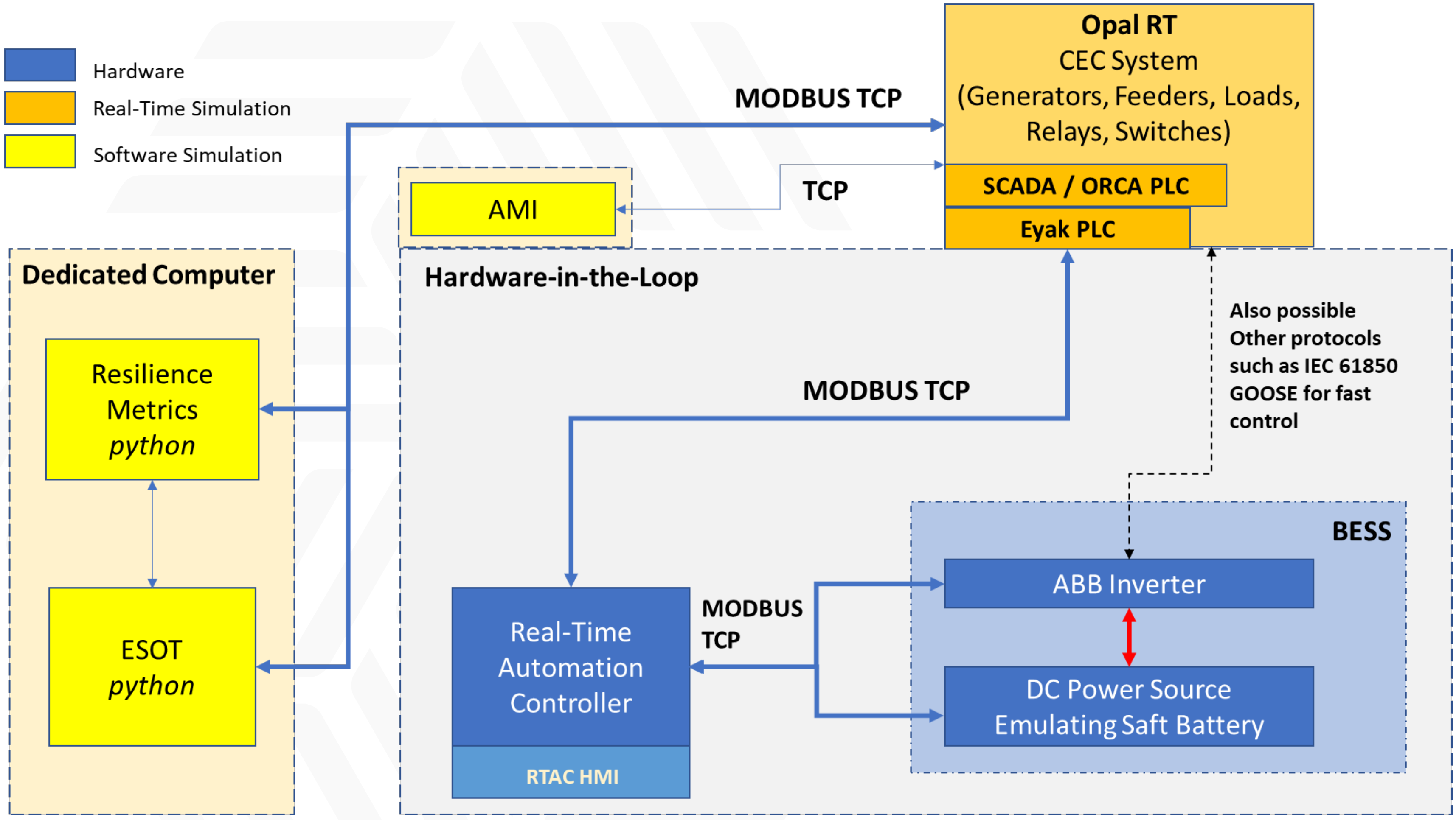
- Real-time data feed
- Relay states controlled remotely via DNP3 and MODBUS
- Follows the SCADA naming convention

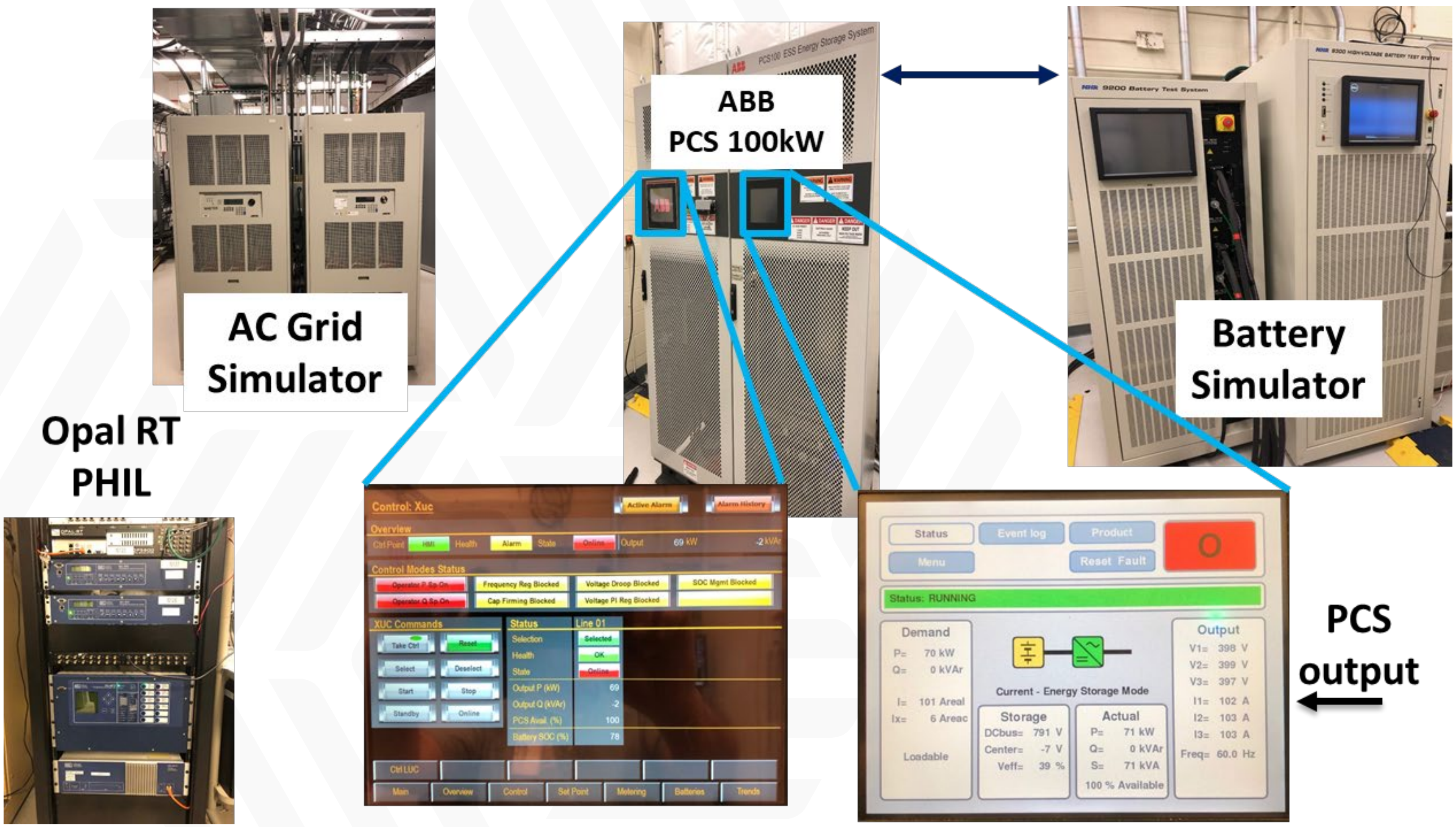


Testing IPT – Status and Approach



Microgrid Design IPT – Status and Progress

Sandia DETL Equipment for Real Time Power Hardware-in-the-Loop Setup



Microgrid Design IPT – Status and Progress

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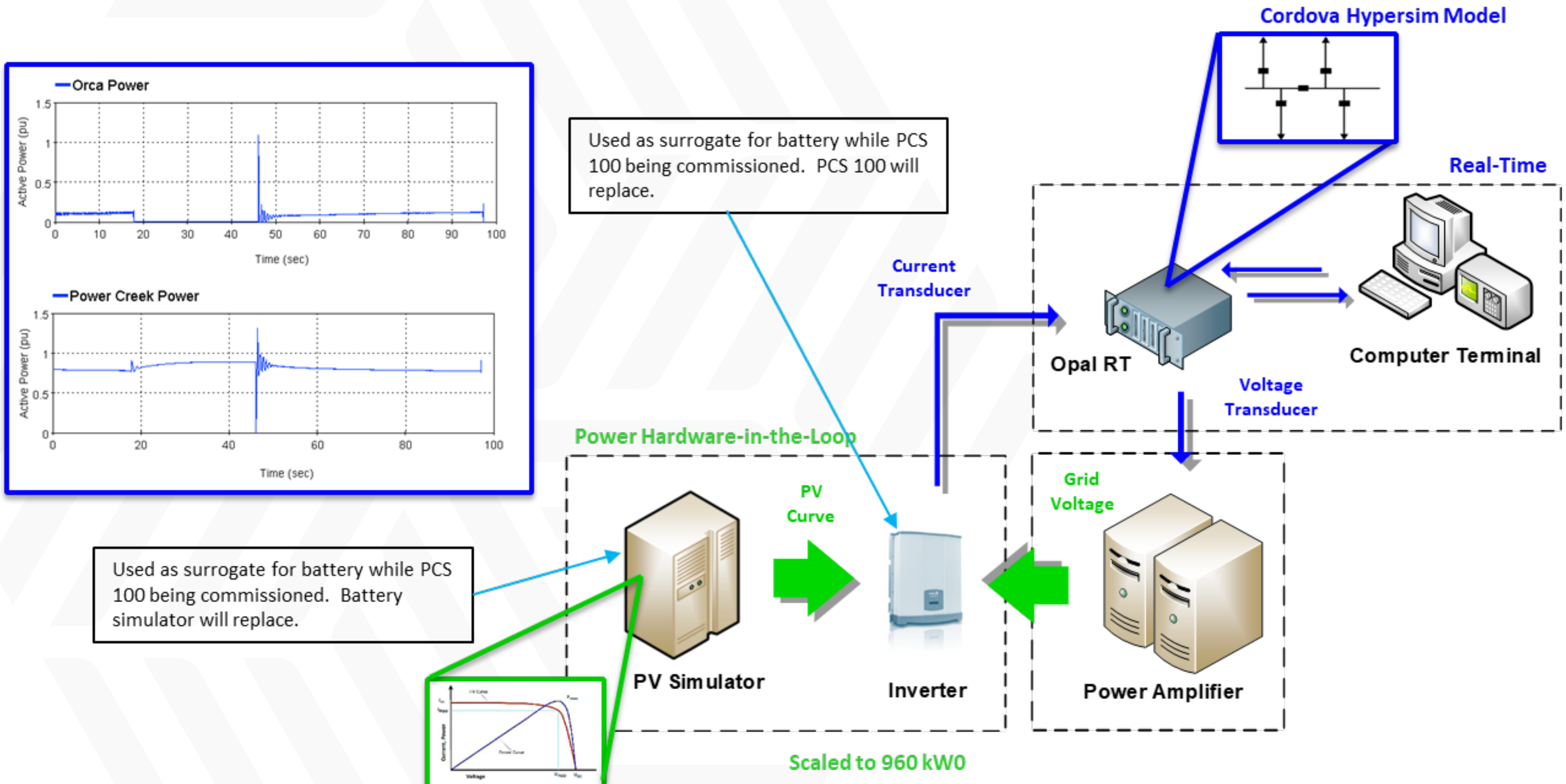

Microgrid Design IPT – Status and Progress

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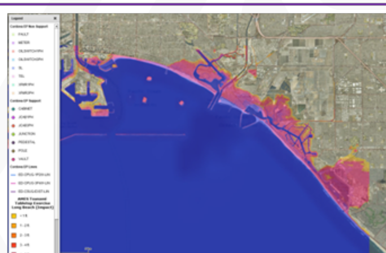
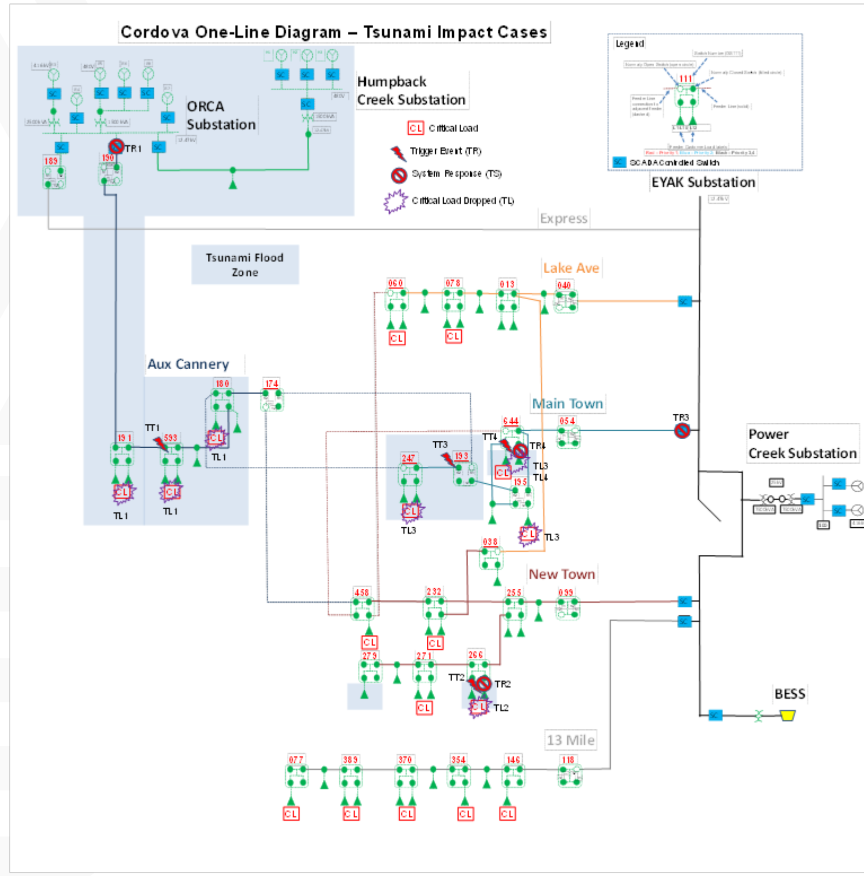
Tsunami Scenarios developed for PSLF and Hypersim PHIL Models

Key Assumptions –

1. Tsunami will inundate certain PMH switchgear
2. A wave of 5-8’ will knock switchgear off the pad
   a. Create a fault
   b. Relay will take feeder out
3. Lower levels of inundation will not cause mechanical damage or fault in switchgear
   a. Water ingress may fault cable at a later time
4. Additional load/generation loss may occur due to voltage/frequency transient
5. Strategic action may involve
   a. De-energizing most vulnerable switchgear
   b. Back-feeding critical load
6. Restoration procedure - case by case



FastMap2015 results for Tsunami for areas with minimum of 3’ of inundation



Microgrid Design IPT – Status and Progress

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Tsunami Warnings, Events and System Responses developed for PSLF and PHIL Models

1. Low Impact –Fault causes loads fuse to trip (TT2, TT4)
2. Medium Impact – Fault causes Aux Cannery or Main Town to trip (TT1, TT3) or ORCA to be forced to shut down (TT5)
3. High Impact – Fault causes ORCA main bus fault taking out, ORCA generation, Aux Cannery and Humpback Creek generation, and express feeder connection to Eyak Substation (TT6)
4. These tsunami trigger event scenarios have been put into both PSLF and Hypersim models for OPAL-RT

Emergency Warning Type	Trigger Event	System Automatic Response or Operator Response	Critical Load Dropped
Tsunami Warning	TT1 - Fault on OS593 (or OS191 or OS180 or feeder conductor)	TR1 - Relays trip Aux Cannery Feeder Breaker at ORCA SS	TL1 - OS191, OS593, OS180
Tsunami Warning	TT2 - Fault downstream of OS266	TR2 - OS266 fuse to loads trip	TL2 - OS266
Tsunami Warning	TT3 - Fault on OS193 (or OS247 or feeder conductor)	TR3 - Relays trip Main Town Breaker at EYAK SS	TL3 - OS193, OS195, OS247, OS644
Tsunami Warning	TT4 - Fault downstream of OS644	TR4 - OS644 fuse to loads trip	TL4 - OS644
Tsunami Warning	TT5 - ORCA substation flooding affects Diesel Generation	TR5 - Operators offload ORCA diesel generation to Hydros and BESS	TL5 - none if sufficient Hydro and BESS capacity exists
Tsunami Warning	TT6 - ORCA substation flooding causes fault on ORCA main bus (most severe contingency)	TR6 - Relays trip Aux Cannery Breaker and Express Breaker at ORCA SS; ORCA and Humpback Creek generation lost; Operators can try to bypass ORCA connection of Humpback Creek to the Express feeder to restore Humpback Creek generation	TL6 - ORCA, Humpback Creek generation; OS191, OS593, OS180 for Aux Feeder; Express Feeder

Microgrid Design IPT – Status and Progress

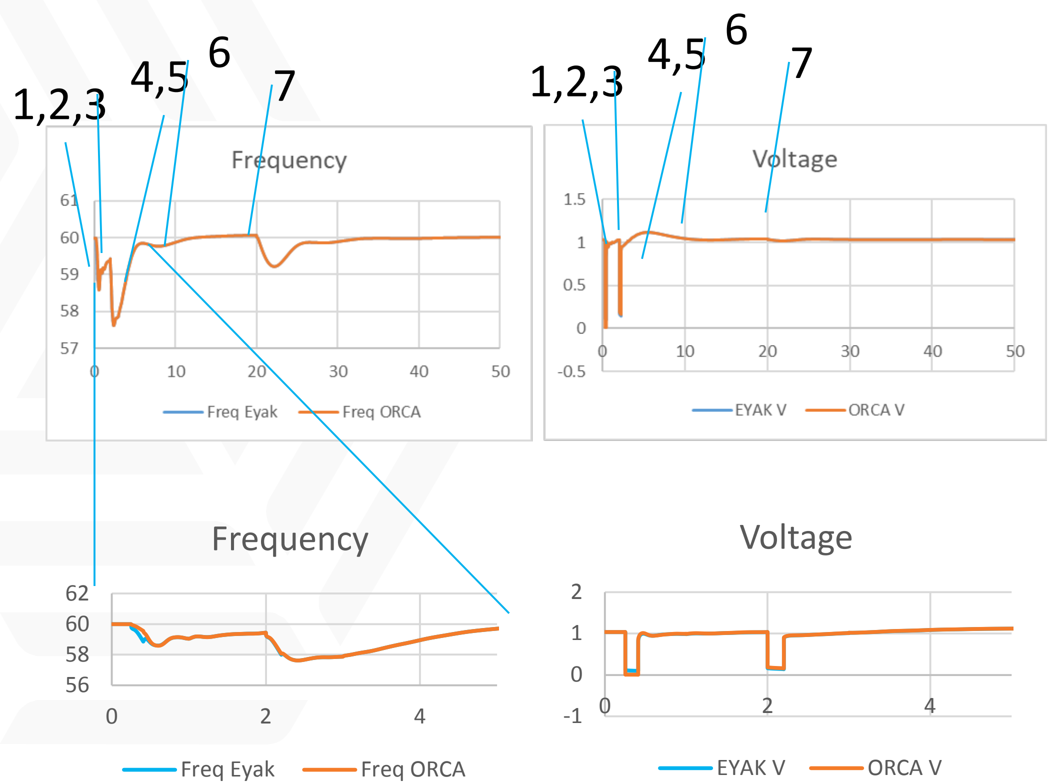
Example Tsunami event with results modeled in PSLF

Purpose:
Provide disturbance results for validation of scenarios/models

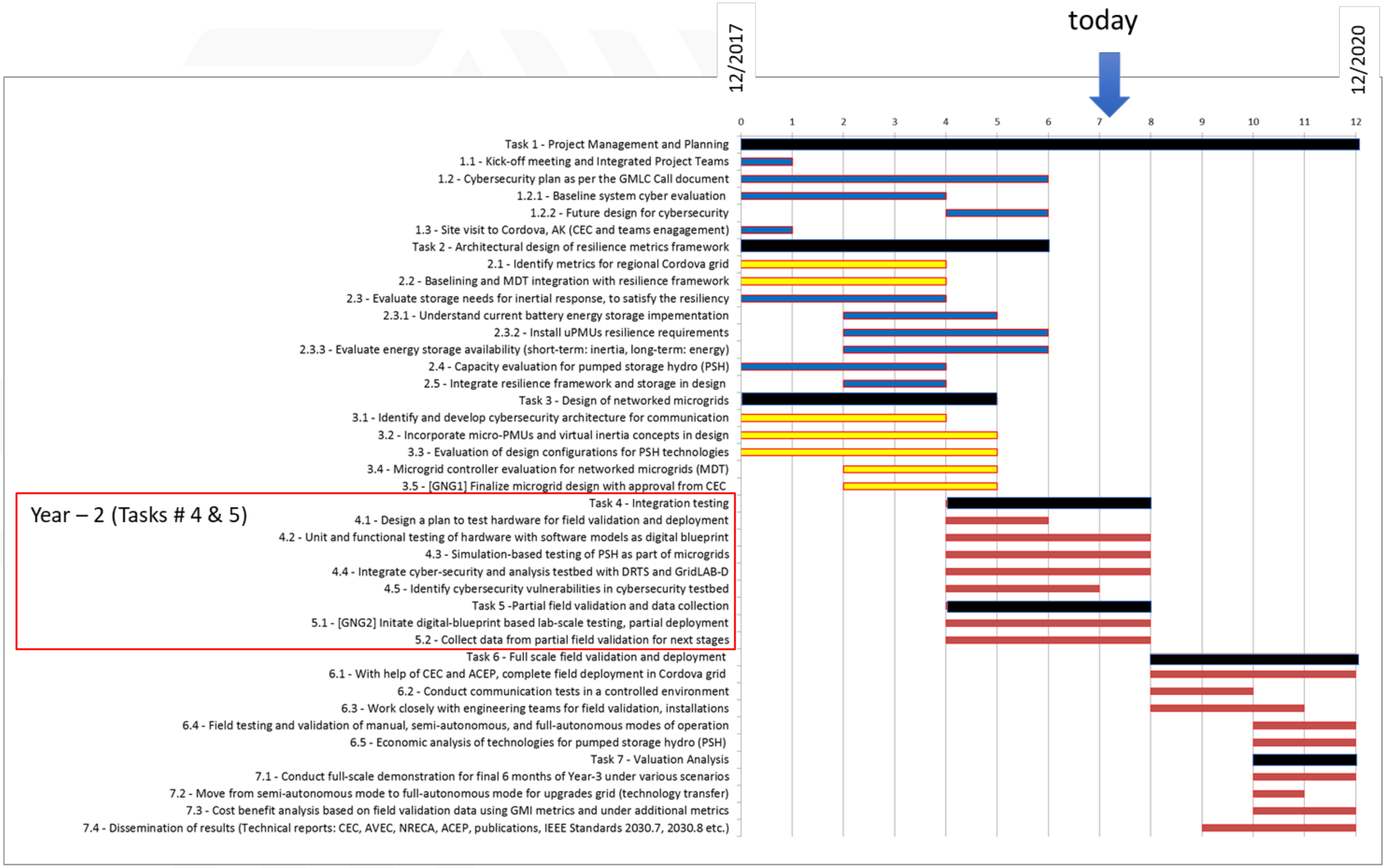
Configuration:
Winter case with all Hydro on-line with diesel at ORCA

Disturbance Sequence:

1. Fault at Canneries
2. Fault cleared- Load Lost at Canneries
3. ORCA diesel unit 7 trips
4. Downstream Fault on New Town Feeder
5. New Town Feeder Fault cleared by Fuse and Recloser at Eyak
6. 13mile feeder trips (underfrequency – 58 Hz 40~delay
7. Newtown feeder back-fed from Lake Avenue



Project Timeline



Project Timeline – Year–2 and Year–3

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Y2

Task 4 - Integration testing
4.1 - Design a plan to test hardware for field validation and deployment
4.2 - Unit and functional testing of hardware with software models as digital blueprint
4.3 - Simulation-based testing of PSH as part of microgrids
4.4 - Integrate cyber-security and analysis testbed with DRTS and GridLAB-D
4.5 - Identify cybersecurity vulnerabilities in cybersecurity testbed
Task 5 -Partial field validation and data collection
5.1 - [GNG2] Initiate digital-blueprint based lab-scale testing, partial deployment
5.2 - Collect data from partial field validation for next stages

Y3

Task 6 - Full scale field validation and deployment
6.1 - With help of CEC and ACEP, complete field deployment in Cordova grid
6.2 - Conduct communication tests in a controlled environment
6.3 - Work closely with engineering teams for field validation, installations
6.4 - Field testing and validation of manual, semi-autonomous, and full-autonomous modes of operation
6.5 - Economic analysis of technologies for pumped storage hydro (PSH)
Task 7 - Valuation Analysis
7.1 - Conduct full-scale demonstration for final 6 months of Year-3 under various scenarios
7.2 - Move from semi-autonomous mode to full-autonomous mode for upgrades grid (technology transfer)
7.3 - Cost benefit analysis based on field validation data using GMI metrics and under additional metrics
7.4 - Dissemination of results
(Technical reports: CEC, AVEC, NRECA, ACEP, publications, IEEE Standards 2030.7, 2030.8 etc.)

Project Timeline – Go/No-Go Milestones

Description	Criteria	Date
Finalize microgrid design with technical inputs, requirements, and final approval from CEC [GNG1 – Subtask 3.5]	Microgrid controller evaluation is completed in line with the technical requirements for networked microgrid operations incorporating energy storage, micro-PMUs, resilience framework, and infrastructure upgrades including communication network design. CEC approves the technical specifications and plans for integration of microgrid controller and system modifications.	Completed 12/11/18
Initiate digital blueprint-based lab-scale testing, and start partial deployment (with help from CEC) of micro-PMUs, other sensors, communication and controls in a selected portion of Cordova grid for testing of microgrid controller functionalities [GNG2 – Subtask 5.1]	Complete the plan for integration of various sensors, hardware equipment, software tools, and models to be tested in a real-time environment for field validation and deployment. Initiate partial field testing in Cordovan microgrids and collect data to iteratively improve the approach.	**Completed 9/30/19**

Project Timeline – Go/No-Go Milestones

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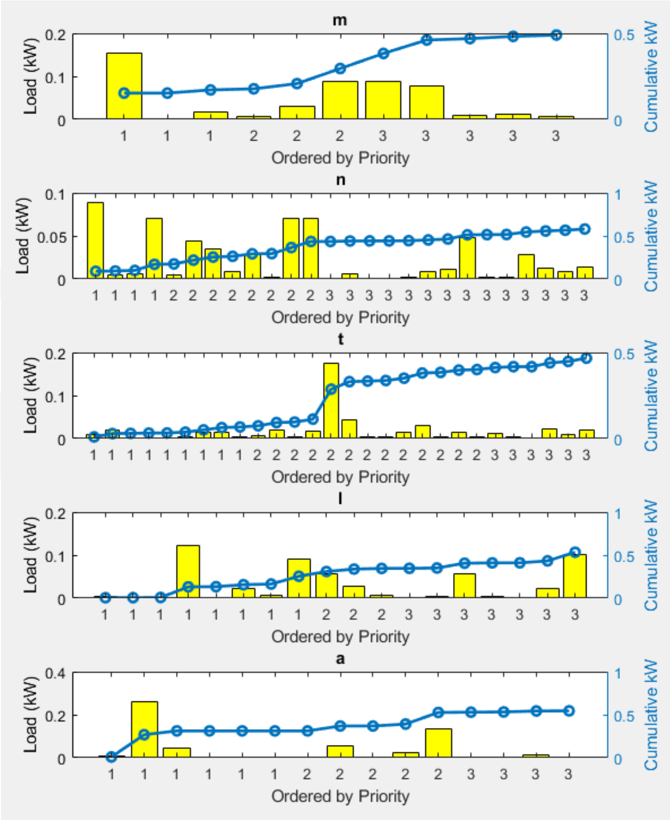
Advanced Metering Infrastructure (AMI) Deployment

- AMI design and deployment planned for FY20.
  - In process to define requirements with help of NRECA, CEC, and vendor.

- Advantages
  - During contingencies: losing a whole feeder vs selective load shedding.
- Two approaches
  - Stacking AMI-based loads in order of priority and selecting
    - Grouping of AMI – *Group-A, Group-B* etc. across feeders
  - Objective function based on priority that define weights
- *Fast* load shedding for stability and demand response as energy services, e.g., *thermostatically controlled loads* (TCLs).
- AMI management platform may provide some analytics to guide these decisions in real-time operation.



RADIANCE
Project Year-2 Key Accomplishments

- In Year-2 of the RADIANCE project, the capabilities at each national laboratory was developed and aligned to minimize the risk of deployment in Cordova, Alaska.
- Developed cyber-physical security testbed, Power Hardware-in-the-Loop for Battery Energy Storage System (BESS), developed digital blueprint coding for Cordova Electric Cooperative microgrid, and Laboratory Valuation Assessment Team methodology was development in support of the GMLC 1.1 Metrics Analysis project.
- RADIANCE team supported OE-funded Sandia-led Battery Energy Storage project in Cordova, AK, and coordinated efforts by working closely with Sandia BESS Team for smooth integration of the BESS in RADIANCE and inputs for Microgrid Design.

RADIANCE
Project Year-2 Key Accomplishments

- ► Cybersecurity plan developments: A “Cybersecurity Plan” was developed for CEC-specific data, and another generic version of the “Cybersecurity Plan” for NRECA and AVEC to share with their electric cooperative members as part of the project deliverables.
- ► Network upgrades for micro-PMU data collection, and microgrid network data was designed and completed as part of Year-2 activities.
- ► Year-3 focus will be the physical deployment of the microgrid per Year-2 design in the field and testing in the field.

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Thank you

Questions?