Security and Resilience
Portfolio Overview

Juan Torres – Security and Resilience Technical Area Lead

Sandia National Laboratories

April 18, 2017
Arlington, VA

Security and Resilience

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

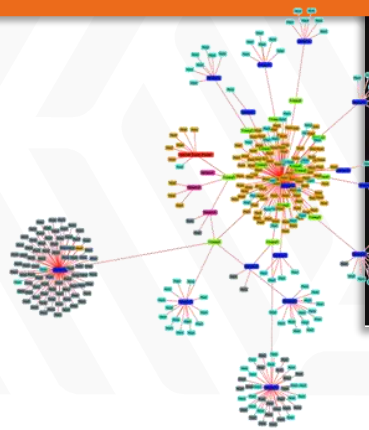
Expected Outcomes

- Holistic grid security and resilience, from devices to micro-grids to systems
- Inherent security designed into components and systems, not security as an afterthought
- Security and resilience addressed throughout system lifecycle and covering the spectrum of legacy and emerging technologies

Federal Role

- Lead and establish security and resilience research programs to develop technology solutions and best practice guidance
- Improve adoption of security and resiliency practices, and provide technology-neutral guidance
- Inform stakeholders of emerging threats and help address threats appropriate for government response

The Challenge:
Threats to the grid are increasing and continually evolving



Program Elements

Based on NIST Cybersecurity Framework

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Identify:

Develop understanding of threats, vulnerabilities, and consequences to all hazards
Outcome: Improved risk management and streamlined information sharing

Protect:

Inherent system-of-systems grid resilience
Outcome: Increase the grid's ability to withstand malicious or natural events

Detect:

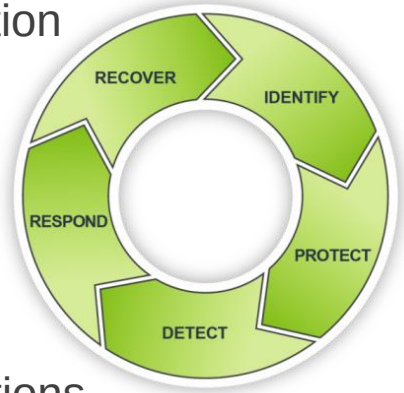
Real-time system characterization of events and system failures
Outcome: Accelerated state awareness and enhanced event detection

Respond:

Maintain critical functionality during events and hazards
Outcome: Advanced system adaptability and graceful degradation

Recover:

Real-time device management and transformer mobilization
Outcome: Timely post-event recovery of grid and community operations



1.3.04 - Industrial Microgrid Analysis and Design for Energy Security & Resiliency

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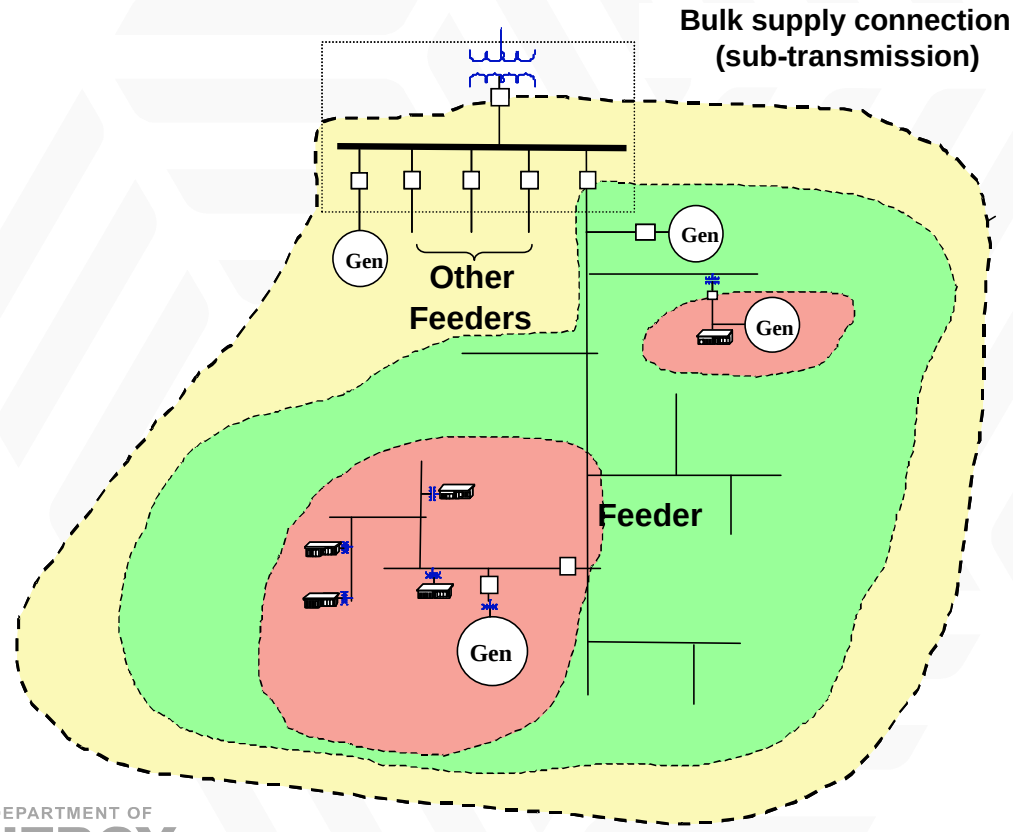
Design and perform cost/benefit analysis of an industrial-scale microgrid with the goal of sharing lessons learned and best practices with other industries and utilities. The analysis will be performed on the UPS Worldport facility in Louisville, Kentucky.



PoP: FY16/17
Budget: $1M
Labs: ORNL, SNL
Partners:

- United Parcel Service
- Waste Management
- Burns & McDonnell
- Harshaw Trane
- Louisville Gas & Electric
- State of Kentucky

1.3.11 - Grid Analysis and Design for Energy and Infrastructure Resilience in New Orleans, LA

GRID MODERNIZATION INITIATIVE
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Supports NOLA's resilience goals by leveraging infrastructure and grid modeling to develop cost-effective grid resilience enhancements for NOLA and the surrounding region. Focused on enhancing grid resilience in order to improve overall community resilience.

PoP: FY16/17
Budget: $1M
Labs: SNL, LANL
Partners:

- City of New Orleans
- Entergy New Orleans
- U.S. Army Corps of Engineers
- 100 Resilient Cities

1.4.23 - Threat Detection and Response with Data Analytics

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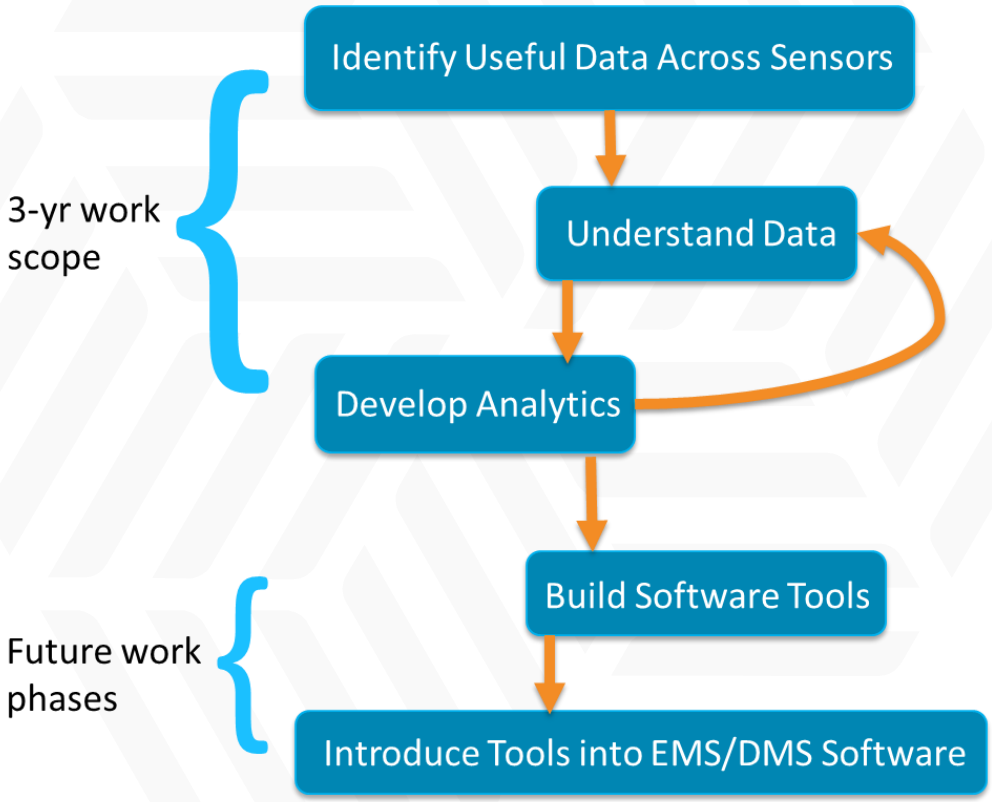
Develop advanced analytics on operational technology (OT) cyber data in order to detect complex cyber threats. Differentiate between cyber and non-cyber-caused incidents using available cyber data.



PoP: FY16/17/18

Budget: $3M

Labs: LLNL, LBNL, INL, ORNL, PNNL, SNL

Partners:

- Electric Power Board (EPB)
- Johnson Controls
- Schweitzer Engineering Laboratories (SEL)

Accomplishments and Emerging Opportunities

GRID MODERNIZATION INITIATIVE
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Accomplishments

- 1.3.04: - Modeling and simulation have resulted in improvements to existing DOE microgrid analysis tools.
- 1.3.11: First ever meeting between partners to collaboratively prioritize resilience-focused grid investments in NOLA.
- 1.4.23: Attack on peak load shaving implemented through direct load control.

Path Forward

- 1.3.04: Complete modeling and final report targeted to utilities and potential industrial users of microgrids.
- 1.3.11: Assure results are broadly available to 100 Resilient Cities and others.
- 1.4.23: Develop analytics for DERs, substations, AMI, buildings, and microgrids that fuse physical and cyber information.

Program Specific Projects

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Energy Systems Risk and Predictive Capability (ESRPC)

- (GM0119) - Improved Forecasts of Electric Outages from Tropical Cyclones (ANL, PNNL)
- (GM0180) - Recommendations for the population, location, and operation of a strategic transformer reserve (ORNL, SNL)
- (GM0217) - Web Tool for Improved Electric Outage Forecasting for Response to Tropical Cyclone Events (LANL, PNNL)

Vehicle Technologies Office (VTO)

- (GM0163) - Diagnostic Security Modules for Electric Vehicle to Building Integration (INL, ANL, NREL, PNNL)

Cybersecurity for Energy Delivery Systems (CEDS)

- (GM0068) - MultiSpeak® - Secure Protocol Enterprise Access Kit (MS-SPEAK) (PNNL)
- (GM0100) - Cybersecurity for Renewables, Distributed Energy Resources, and Smart Inverters (ANL)

Smart Grid (SG)

- (GM0131) - A Closed-Loop Distribution System Restoration Tool for Natural Disaster Recovery (ANL, BNL)

Solar Energy Technology Office (SETO)

- (SI1541) - Secure, Scalable, Stable Control and Communications for Distributed PV (SNL)

Summary

- Security and Resilience is critical to grid modernization
- Program elements aligned with NIST Cybersecurity Framework
- Foundational/Partnership Projects
  - 1.3.04: Industrial microgrid – KY
  - 1.3.11: Infrastructure resilience – NOLA (Complete)
  - 1.4.23: Threat detection with data analytics – distinguish cyber attacks from physical and other signatures
- Eight program specific projects
- Accomplishments and Emerging Opportunities

GMLC 1.3.11 - Grid Analysis and Design for Energy and Infrastructure Resilience in New Orleans, LA

ROBERT JEFFERS, SANDIA NATIONAL LABORATORIES

April 18-20, 2017

Sheraton Pentagon City – Arlington, VA

1.3.11 Grid Analysis and Design for Energy and Infrastructure Resilience in New Orleans, LA

High Level Summary

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

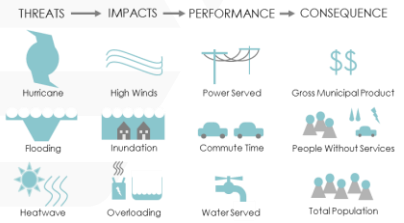
Supports NOLA's resilience goals by leveraging infrastructure and grid modeling to develop cost-effective grid resilience enhancements for NOLA and the surrounding region.
Focused on enhancing grid resilience in order to improve overall community resilience.

Value Proposition

- ✓ Technical assistance from the national labs can be the catalyst for collaborative resilience planning between utilities and cities
- ✓ We are showing how investments in grid modernization improve community resilience, and how these investments can be prioritized

Project Objectives

- ✓ Improved understanding of how infrastructure and community resilience are dependent on grid performance in NOLA
- ✓ A set of risk-informed cost-effective recommendations for grid enhancements that improve NOLA community resilience
- ✓ Conceptual designs utilized by NOLA, Entergy, and others to prioritize energy infrastructure improvement options
- ✓ A utilization of existing DOE security and resilience research to improve real-world community resilience



Project Team

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
SNL	800k	0	0
LANL	200k	0	0

Project Participants and Roles

SNL

- Project manager, infrastructure resilience analysis, grid prioritization and design

LANL

- Hurricane modeling, grid impact analysis

City of New Orleans

- Multiple offices providing subject matter expertise, data, prioritization

Entergy New Orleans

- Electric utility for NOLA, subject matter expertise, data, potential implementation

US Army Corps of Engineers

- Subject matter expertise and threat characterization reviewer

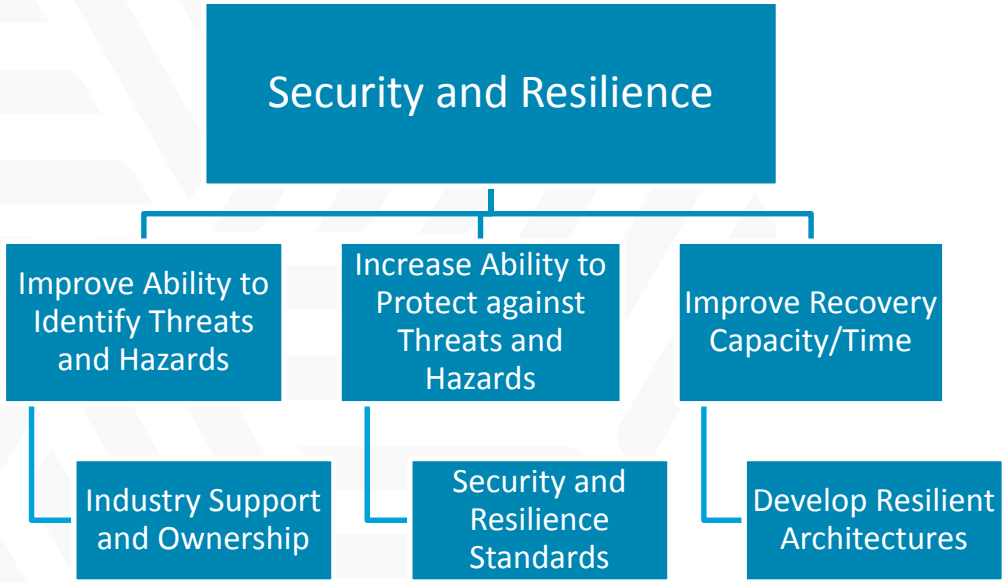
100 Resilient Cities

- Catalyst for partner collaboration, information dissemination and outreach

Relationship to Grid Modernization MYPP

Addresses the Security & Resilience technical area by focusing on:

- Improving the Ability to **Identify** Threats and Hazards
- Improving the Ability to **Protect** Against Threats and Hazards
- Improving the Time and Capacity to **Recover**



Approach

- Infrastructure Impact Modeling and Analysis
  - Model high-consequence hurricane impacts to the grid and critical infrastructure services
  - Populate a baseline resilience metric useful to project partners and stakeholders
- Design and Integration of Grid Modernization Options
  - Suggest grid resilience improvement portfolios that improve community resilience
  - Show the improvement in resilience metrics
- Resilience Cost/Benefit
  - Ensure grid resilience improvements are cost effective for the intended resilience benefits
- Transactive Control Feasibility
  - Explore how building/customer resources can be engaged through a transactive energy scheme to provide energy and infrastructure resilience

1.3.11 Grid Analysis and Design for Energy and Infrastructure Resilience in New Orleans, LA

Key Project Milestones

GRID MODERNIZATION INITIATIVE
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Milestone (FY16-FY18)	Status	Due Date
Briefing to NOLA stakeholders on infrastructure resilience analysis	Complete	6/29/16
Outline of transactive controls feasibility study	Complete	6/29/16
Draft report to NOLA stakeholders and DOE on infrastructure resilience analysis	Complete	8/18/16
Draft report of transactive controls feasibility study	Complete	10/18/16
Briefing to NOLA stakeholders on grid modernization options for NOLA resilience	Complete	10/26/16
Draft report to NOLA stakeholders and DOE on grid modernization options for NOLA resilience	Complete	11/29/16
Finalize transactive controls feasibility study	Complete	12/15/16
Finalize grid modernization for NOLA resilience analysis, including cost/benefit metrics	Complete	1/15/17
Draft unclassified, unlimited release report providing project overview and key findings	Complete	2/15/17

Accomplishments to Date

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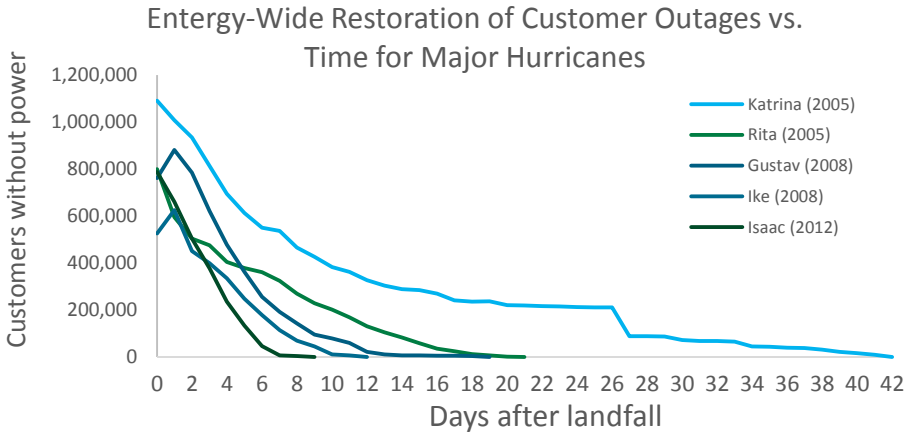
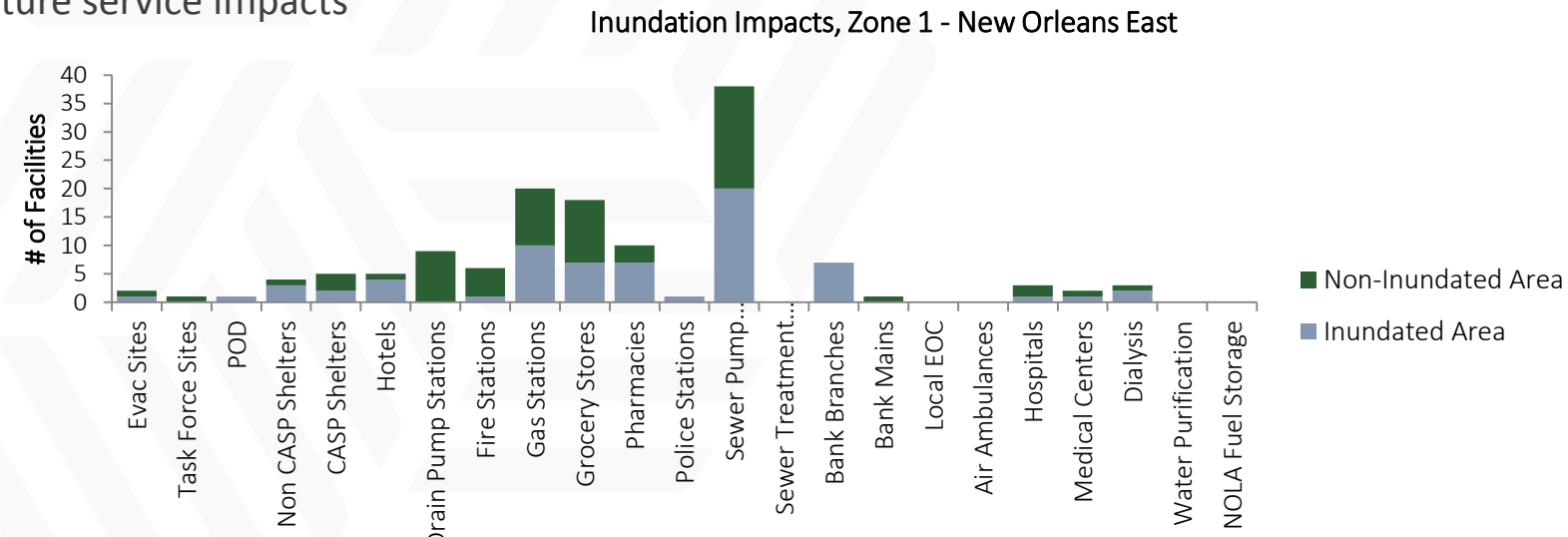
Baseline Resilience of NOLA:

- Improvements since Katrina result in large decrease of surge-induced flood risk (e.g. levee failures and overtopping)
- Widespread power outage expected, potentially transmission-driven but certainly distribution damage and recovery
- Different communities experience different infrastructure service impacts





Accomplishments to Date

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Grid Improvements for Community Resilience:

- Selected to provide greatest support to critical community services for the greatest number of citizens
- Greatest grid modernization focus on microgrids

Collaborative planning for grid investment to support community resilience:

- First ever meeting between partners to collaboratively prioritize resilience-focused grid investments in NOLA
- Also including non-resilience benefits in the prioritization, such as reliability, community engagement, support for underrepresented or underprivileged communities

1.3.11 Grid Analysis and Design for Energy and Infrastructure Resilience in New Orleans, LA
Response to December 2016 Program Review

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Recommendation	Response
Coordinate with Institutional Support Team	Discussing how to use NOLA as exemplar for Valuation and Future Regulation projects (with support from 1.1 Metrics)
Inform the development of metrics regarding resilience. Coordinate with 1.1	Project 1.1 is using NOLA as one of their year 2 exemplars
Make sure the deliverable will be accessible to other cities in 100RC network	The open access report is finalized and progressing through review and approval now. We are actively engaged with 100RC.
Confer with other microgrid projects (AK, KY) to see if need for coordination	Sharing lessons learned
Work with communications team on success stories	Yes – working with Kelly Yee on this

Project Integration and Collaboration

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Project Integration:

1.1 Foundational Metrics

- Our work is a baseline for year 2 proof of concept for resilience and reliability metrics

1.3.4 Industrial Microgrids

- Sharing lessons learned on how to translate system-level needs to optimal designs

1.4.23 Threat Detection…

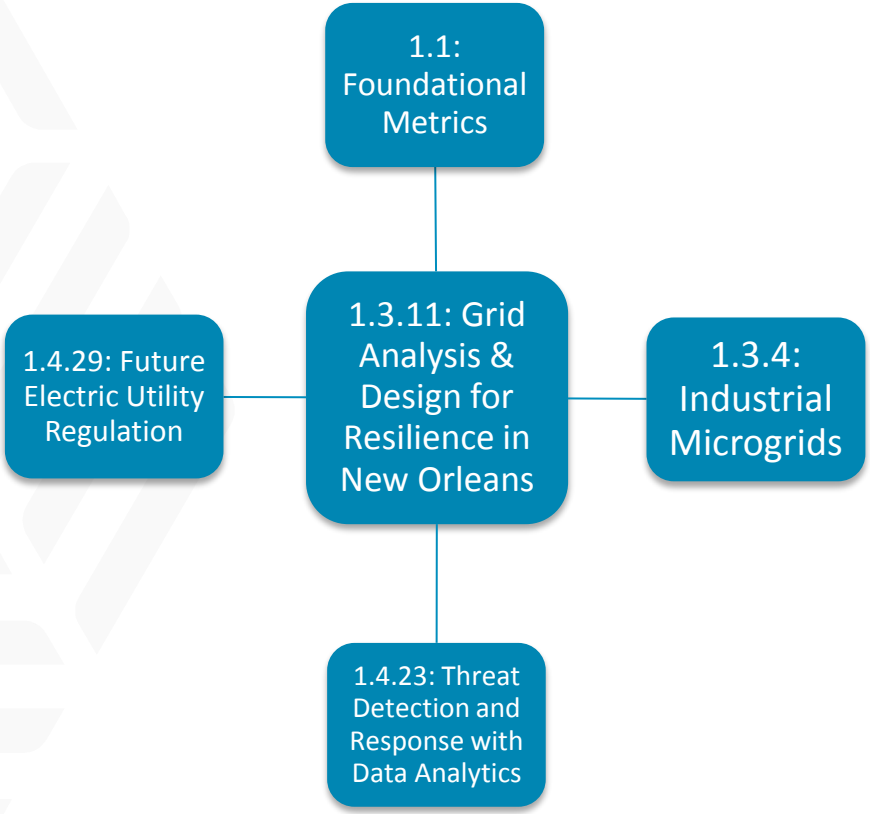
- Sharing lessons learned on connection between improvements in threat detection and resilience

1.4.29 Future Regulation

- Discussing how to provide Entergy with regulatory resilience incentives w/in NOLA's framework

Communications:

- Presented to Sandia external advisory board on Resilience in Complex Systems
- Updates shared with 100 Resilient Cities on numerous occasions



Next Steps and Future Plans

This project is complete, however:

1. SNL and City of NOLA are working with HUD and 100RC to identify funding mechanisms for microgrids (three specific avenues identified). Use of NOLA's existing NDRC funding is also being discussed. Dept of Transportation a new avenue not yet pursued.

2. SNL and Entergy are discussing multiple avenues to support microgrids and resilience in NOLA

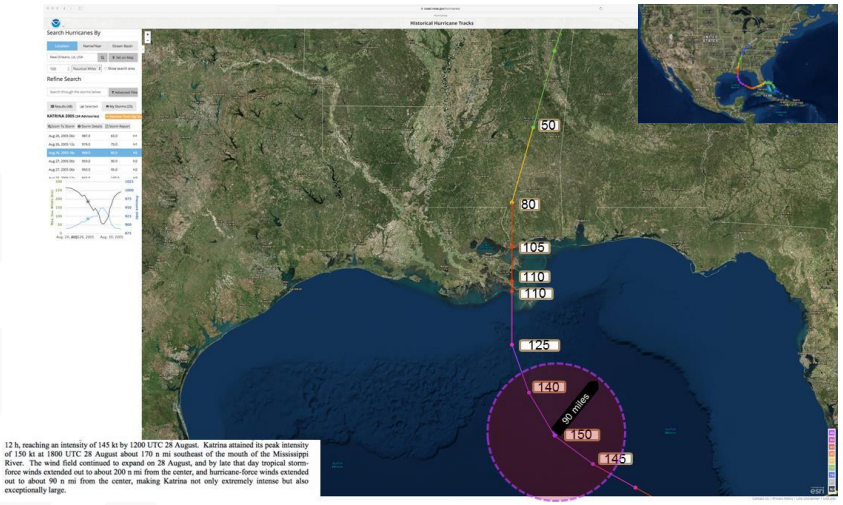
3. SNL on GMLC 1.1 (Metrics) is working to support Entergy and NOLA in improving confidence in the necessary metrics to make prioritization decisions

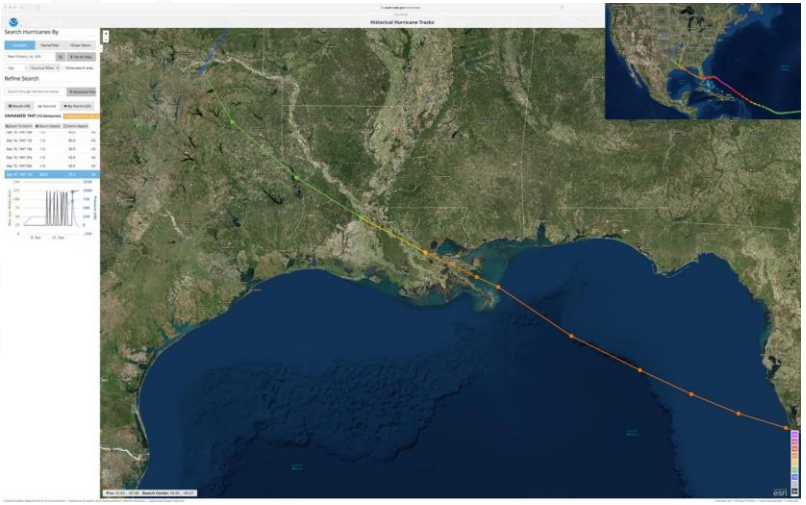
4. Discussion with Institutional Support about City of NOLA's interest in Technical Assistance for alternative regulatory schemes and valuation of microgrids

Technical Details

Contrasting *Worst Consequence* with *Worst Threat* analysis

- In NOLA, the worst likely consequence is a high category 2 that may strengthen to a category 3 just before landfall
  - NOLA's policy is to call for mandatory evacuation for cat 3 and higher
- 20" or more of rain in 24 hours
- Dewatering system performance impacted by storm
- Two types of trajectories identified





1.3.11 Grid Analysis and Design for Energy and Infrastructure Resilience in New Orleans, LA

Technical Details

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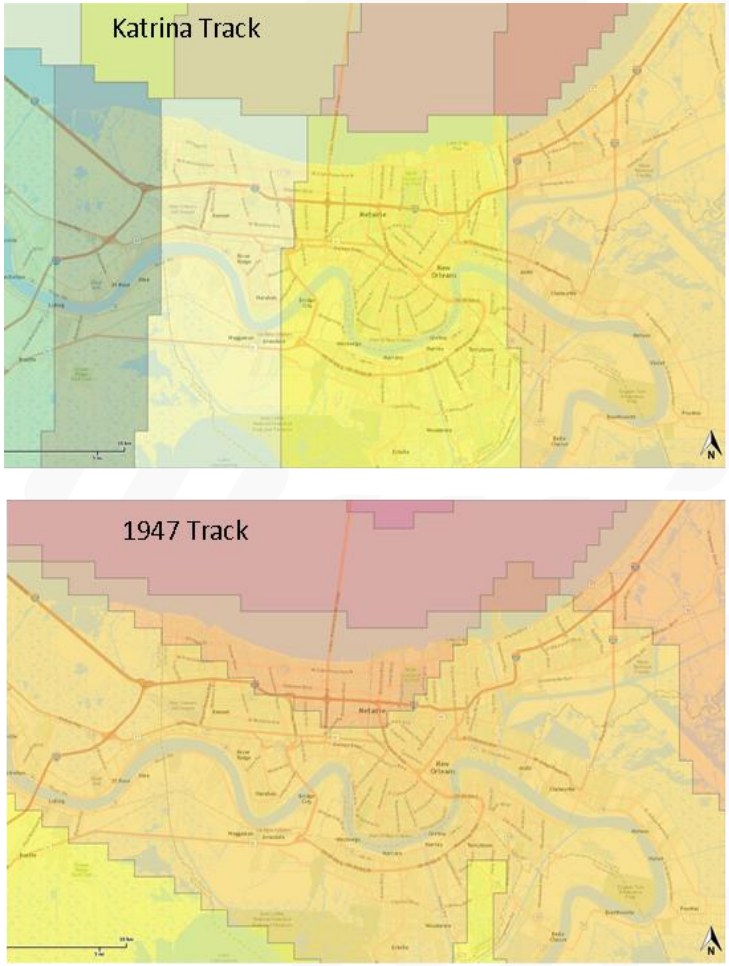
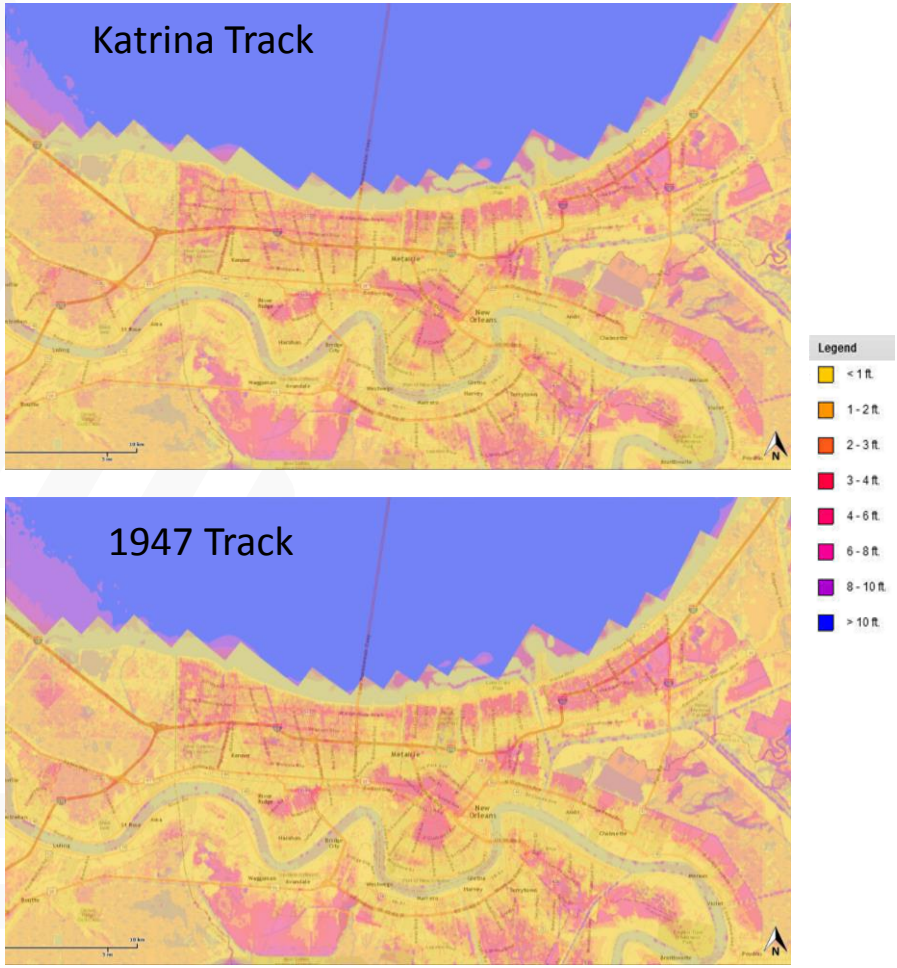
- Wind:

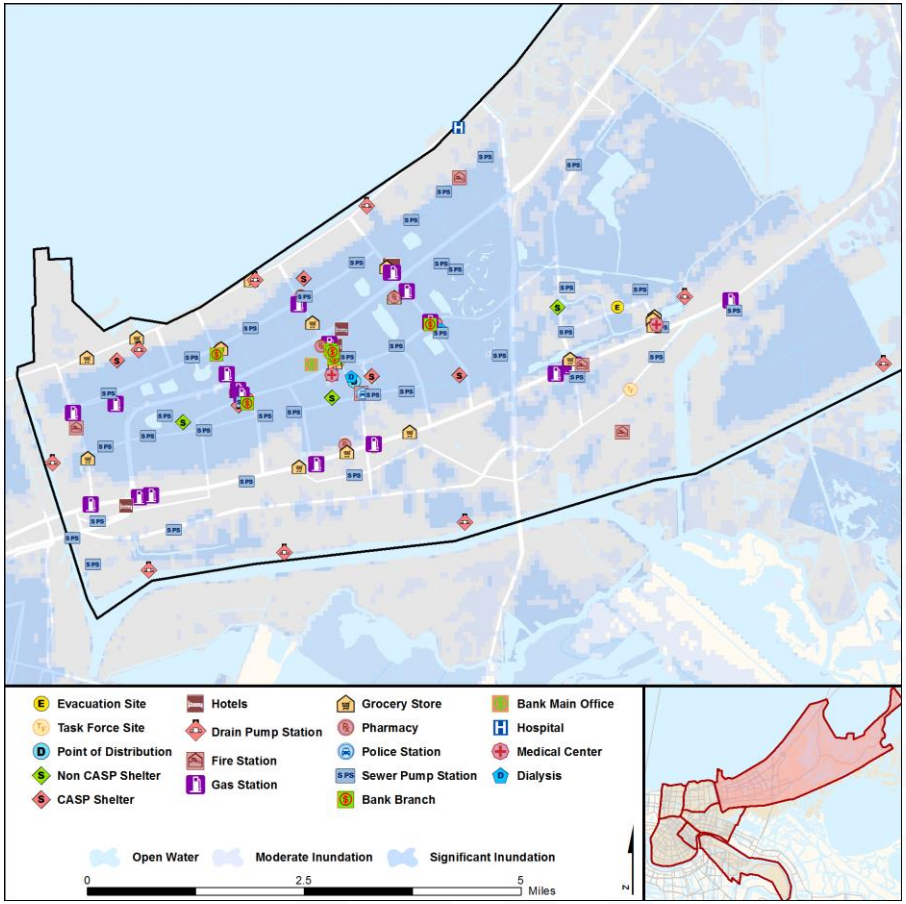


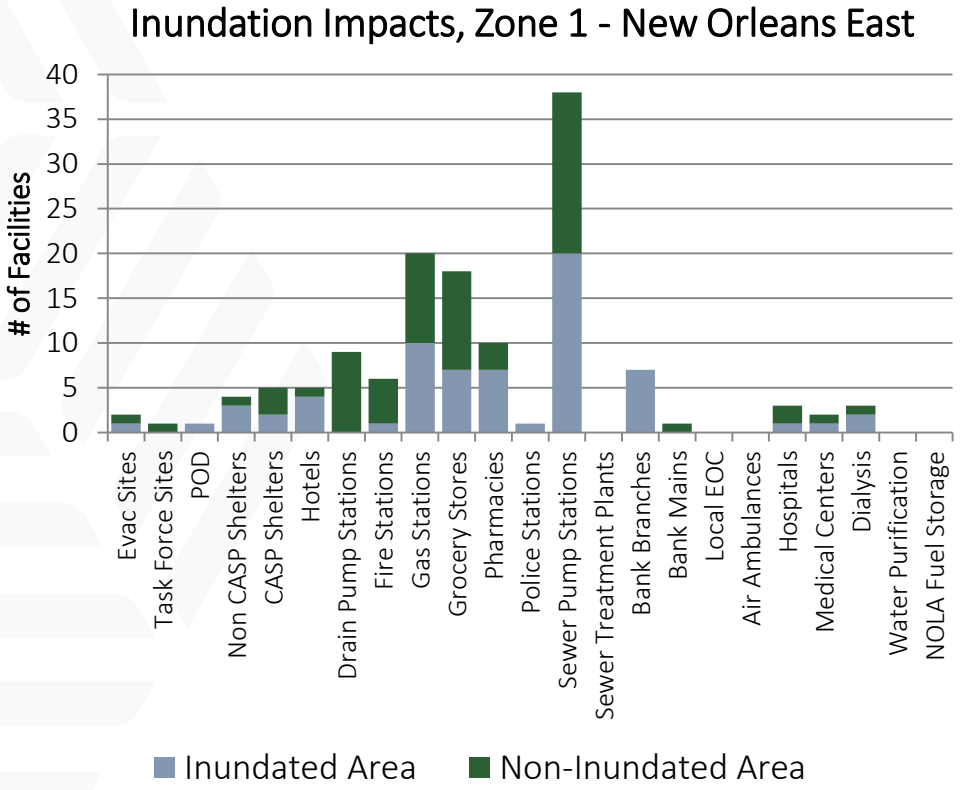
- Inundation:



Technical Details

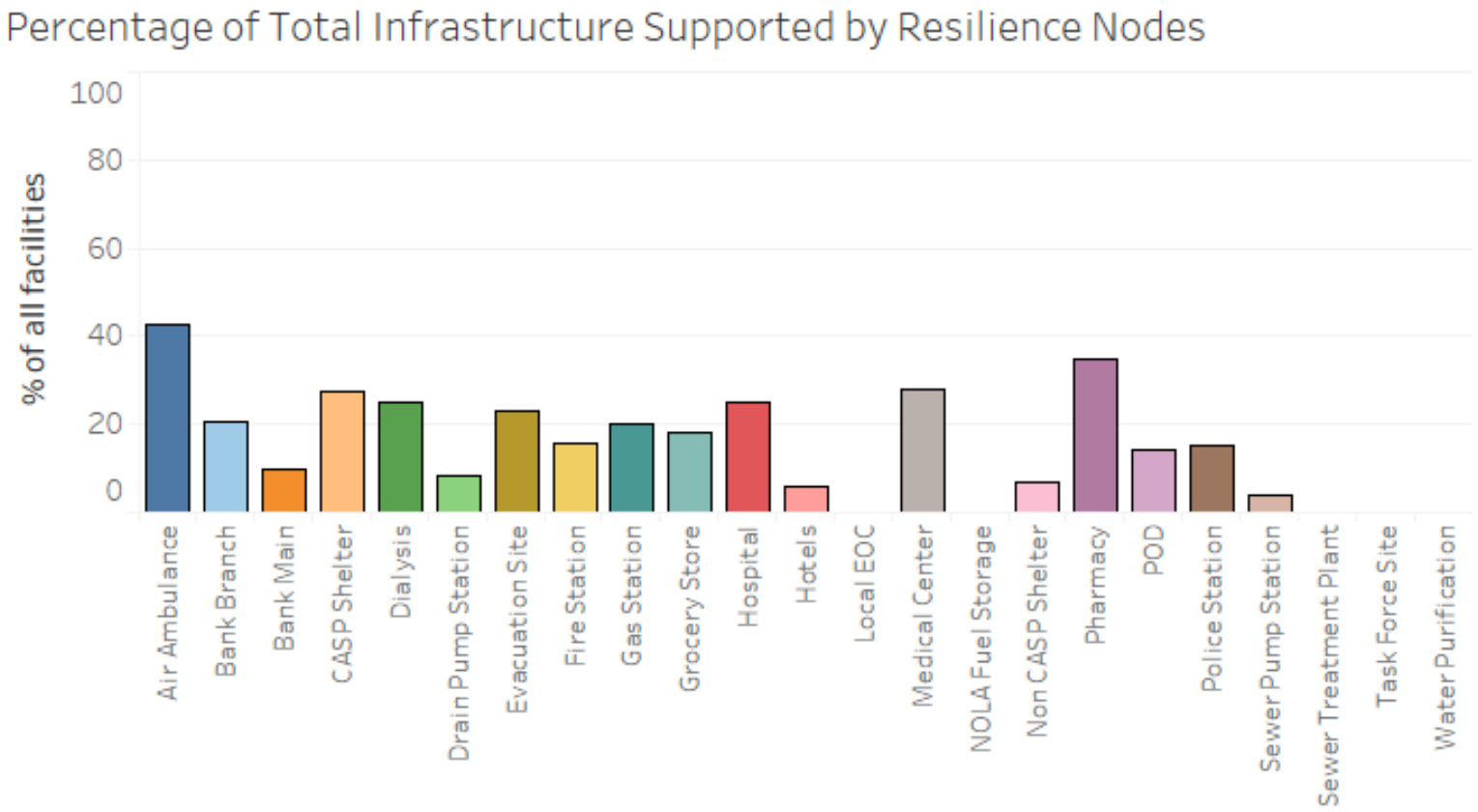
- Example analysis zone, New Orleans East:
  - Goal is to provide infrastructure services to a broad set of needs and locations





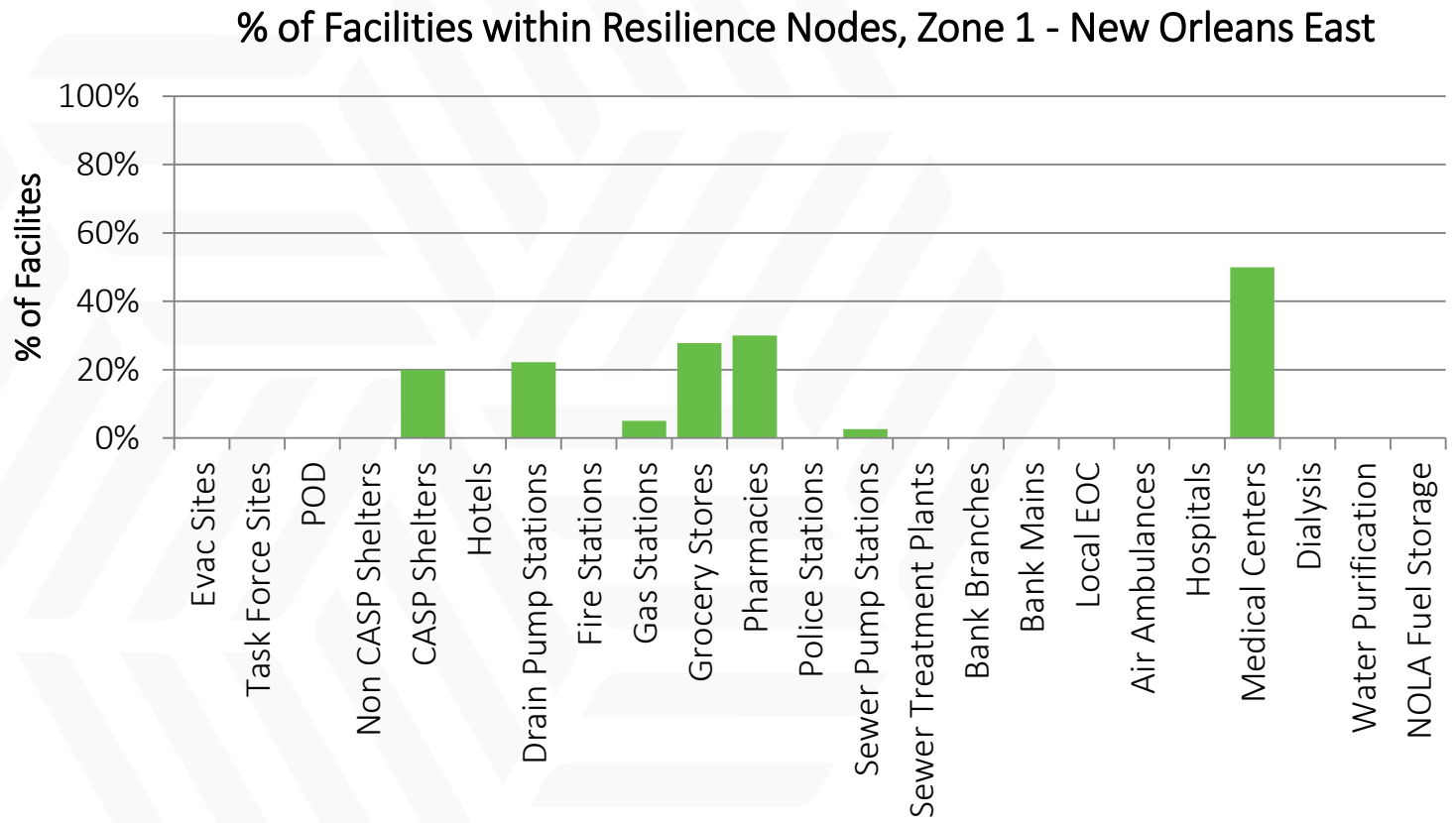
Technical Details

- City wide impact if all resilience nodes supported by microgrids



Technical Details

- Example analysis zone, New Orleans East



GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.3.4 – Industrial Microgrid Analysis and Design for Energy Security and Resiliency

BEN OLLIS – OAK RIDGE NATIONAL LABORATORY

April 18-20, 2017

Sheraton Pentagon City – Arlington, VA

Industrial Microgrid Analysis and Design for Energy Security and Resiliency

High Level Summary

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

ORNL and SNL will design and perform cost/benefit analysis of an industrial-scale microgrid with the goal of sharing lessons learned and best practices with other industries and utilities. The analysis will be performed on the UPS Worldport facility in Louisville, Kentucky.

Project Objectives

- ✓ All-hazards risk analysis of facilities
- ✓ Cost/benefit analysis of industrial-scale microgrids
- ✓ Potential for grid services provision
- ✓ Roadmap to industrial microgrid deployments & lessons learned

Value Proposition

- ✓ Industrial utility customers often spend hundreds of thousands to millions of dollars in backup systems and standby generation in case of sudden loss of electricity supply due to outside influences such as severe storms.
- ✓ Utilities stand to benefit from the modernized grid, however they are often hesitant to invest in new technologies.
- ✓ This project aims to demonstrate reliability improvements for industrial customers can also benefit utilities and provide a methodology applicable to other areas of the country.

Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Project Team

Project Participants and Roles

ORNL – Lead, Efficiency and Ancillary Services Analysis
SNL – Microgrid Design, Cost/Benefit Analysis
UPS – Industry Partner
Waste Management – Industry Partner
Prime Time Computing – Risk Analysis
Burns & McDonnell – Support, *Biogas analysis*
Harshaw Trane – Support, *Biogas analysis*
Kentucky Government - Support

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
ORNL	$600k	$0k	N/A
SNL	$400k	$0k	N/A

Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Relationship to Grid Modernization MYPP

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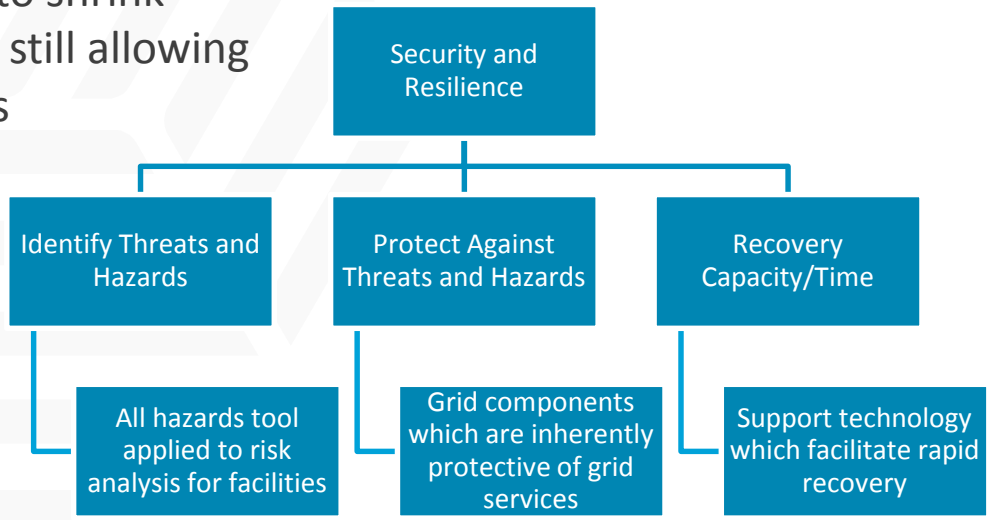
Utilizing an all-hazards approach for risk assessment of the Louisville area and UPS facilities

Taking steps to address specific electrical risk through the use of microgrid(s)

Looking at reduced capacity operations to shrink investment in microgrid resources while still allowing facilities to operate during contingencies



Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Approach

- Task 1 – Microgrid Evaluation
  - Analyze three critical industrial facilities with open-source software and provide a narrowed search space of microgrid options
- Task 2 – Risk Analysis
  - Utilize an all-hazards tool to determine current risk and risk reduction as a result of the project
- Task 3 – Energy Efficiency and Ancillary Services
  - Utility rate structures used to identify most valuable services to the grid
- Task 4 – Generation Upgrades
  - Options for combined head and power (CHP) for electrical generation and heat load requirements
- Task 5 – Energy Resiliency and Cost/Benefit Optimization Modeling and Analysis
  - Cost/benefit study for three microgrids serving critical operations

Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Key Project Milestones

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Milestone (FY16-FY18)	Status	Due Date
Kickoff Meeting with Stakeholders	Complete	4/12/16
Initial Microgrid Design	Complete – 1 site	10/1/16
Risk Analysis Completed	Complete - Preliminary	4/1/17
Contracts in Place for Biogas Analysis	On Hold	4/1/17
Energy Efficiency and Ancillary Service Analysis	In Progress	10/1/17
Generation Upgrades Analysis	In Progress	10/1/17
Cost/Benefit Modelling and Analysis	Complete – 1 site	10/1/17

Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Accomplishments to Date

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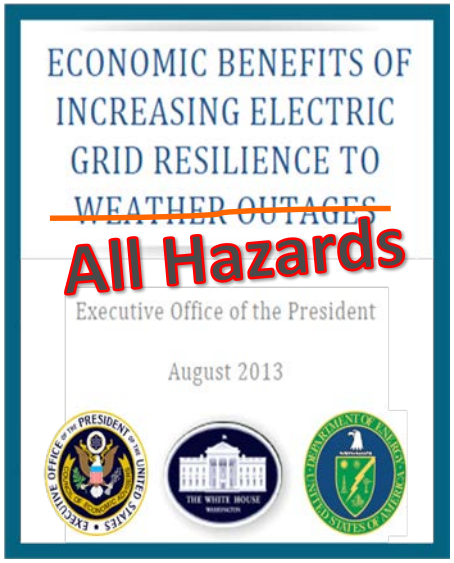
U.S. Department of Energy

- Analysis utilizes open-source software
- Two site visits to UPS Worldport to tour facilities and infrastructure
- Met with utility and industry stakeholders to discuss rate programs and partnerships
- Identified critical industrial and electrical infrastructure
- Performed microgrid analysis on a critical industrial facility
- Data collection underway for two more microgrid sites
- Modelling and simulation have resulted in upgrades to existing DOE tools



Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Accomplishments to Date

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Option	Facility A	Facility B	Tie	Cost ($K)	Overall Availability (Ci)	Post-Startup Availability (Ci)	Post Startup Occurrences with Load Loss (Ci)	Overall Diesel Efficiency
Baseline	550 kW	550 kW	No	$740,000	97.909024%	97.914717%	4.67%	24.03%
Baseline with Tie	550 kW	550 kW	Yes	$1,255,000	99.989214%	99.995262%	4.55%	25.91%
Baseline with Additional Facility A Gen	550 kW (x2)	550 kW	No	$1,509,500	98.879204%	98.88567%	2.91%	24%
Baseline with Additional Facility B Gen	550 kW	550 kW (x2)	No	$1,509,500	98.222782%	98.228565%	3.18%	23.7%
Baseline with Additional A & B Gen	550 kW (x2)	550 kW (x2)	No	$2,279,000	99.939886%	99.945881%	1.02%	23.96%
Facility A Microgrid	550 kW (x2)	550 kW	Yes	$2,024,500	99.993829%	99.999745%	2.59%	25.82%
Facility B Microgrid	550 kW	550 kW (x2)	Yes	$2,024,500	99.994035%	99.999988%	0.15%	25.72%
Facility A-B Microgrid	550 kW (x2)	550 kW (x2)	Yes	$2,794,000	99.993963%	99.999995%	0.2%	25.69%

Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Response to December 2016 Program Review

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Recommendation	Response
Please look into using the "Solar Glare Hazard Analysis Tool" to address any issues for integrating solar technologies near the airfield.	The tool has been investigated and discussed with UPS, and currently there is no issue with airfield solar as it pertains to pilot safety.
Please make the deliverable applicable and accessible to others looking to implement microgrids.	Opportunities to make the results more generic are considered while performing testing. The final report will attempt to convey how the results could be applicable to others in industry.

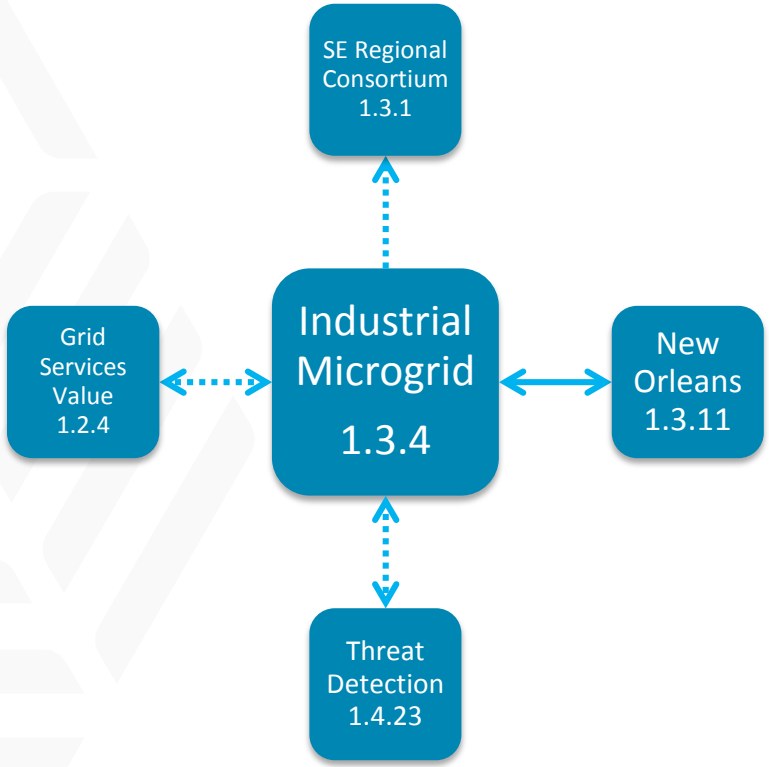
Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Project Integration and Collaboration

Communications:

Currently no forums or publications have been public, due to the business sensitive nature of the data and electrical diagrams. A document approved for public release will be made available at the conclusion of the project.

Due to the short nature of this project, we hope to share lessons learned and results with other GMLC projects.



Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Next Steps and Future Plans

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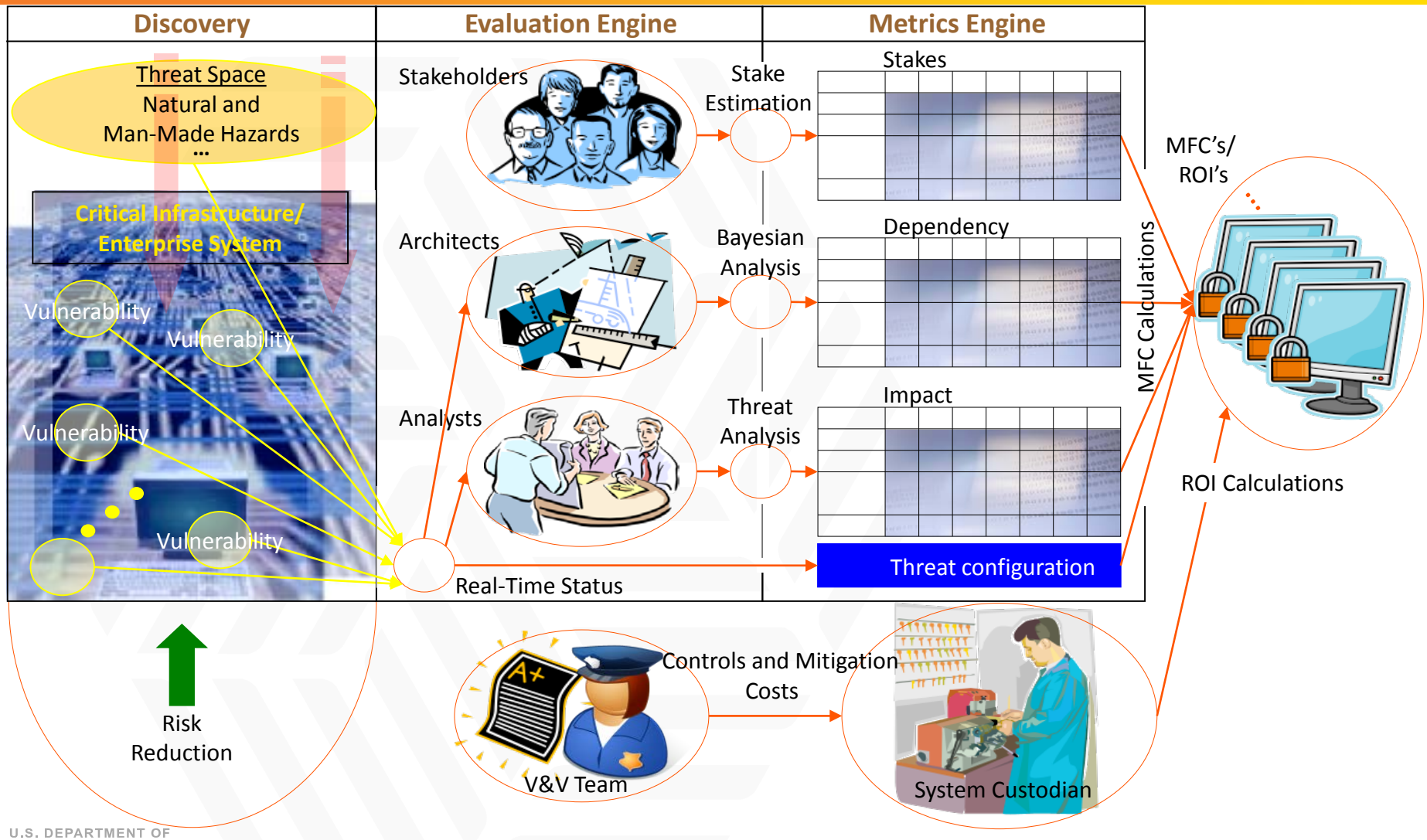
- The lab team will continue to refine results based on new data
- Real-time modelling and CHP analysis is underway and should be ready to test in the coming months
- Final report completed by end of FY17
  - Targeted at other industries and utilities interested in microgrids for critical industrial facilities.
- Aim to deliver the results to the hands of industrial consumers and utilities interested in microgrids to stimulate conversation on grid modernization.
- Expect results can be used as lessons learned for other grid modernization projects

Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Technical Details



Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Technical Details

$$Y_i = \sum_{i \le j \le m} X^j \times A_i^j, 1 \le i \le n$$

Y: vector of size n
X: vector of size m
A: n×m matrix

$$Y = A \circ X$$

$$MFC(S_i) = \sum_{R_j} FC_{i,j} \times P(R_j)$$

ST: Stakes Matrix
PR: vector of requirement failure probabilities

$$MFC = ST \circ PR$$

$$P(R_i) = \sum_{j=1}^{k+1} \pi(R_i|E_j) \times \pi(E_j)$$

DP: Dependency Matrix
PE: vector of component failure probabilities

$$PR = DP \circ PE$$

$$\pi(E_i) = \sum_{j=1}^{h+1} \pi(E_i|V_j) \times \pi(V_j)$$

IM: Impact Matrix
PT: vector of threat emergence probabilities

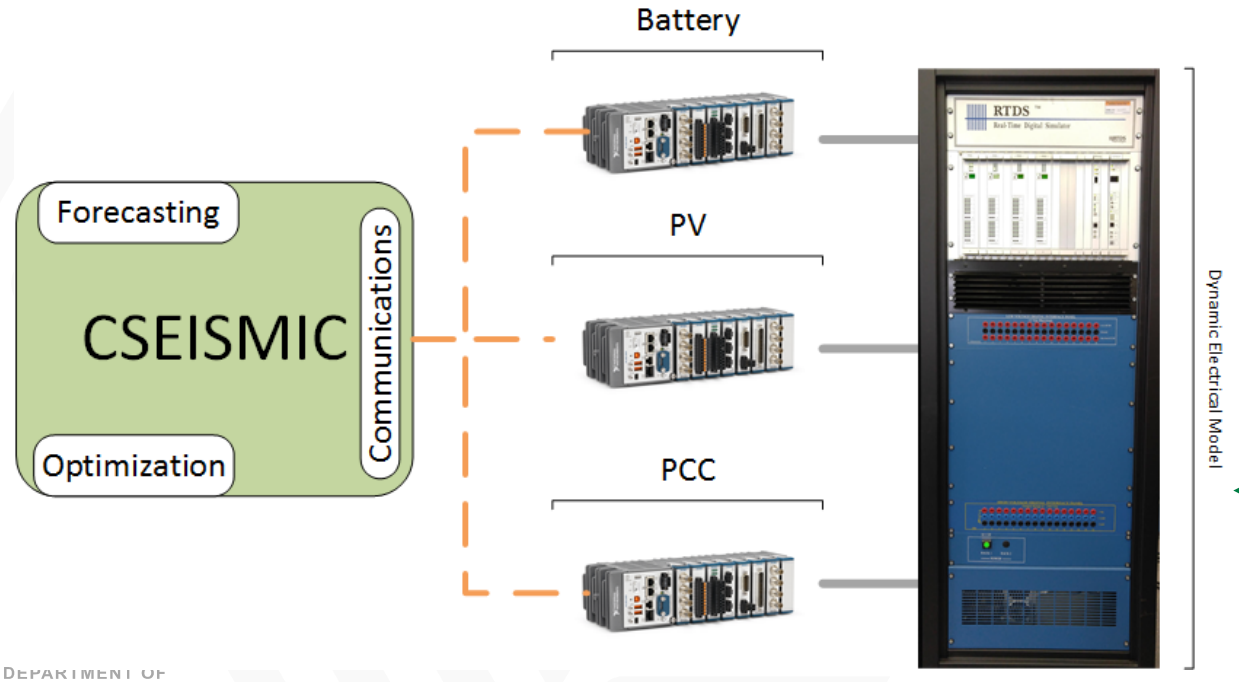
$$PE = IM \circ PT$$

$$MFC = ST \circ DP \circ IM \circ PT$$

Industrial Microgrid Analysis and Design for Energy Security and Resiliency

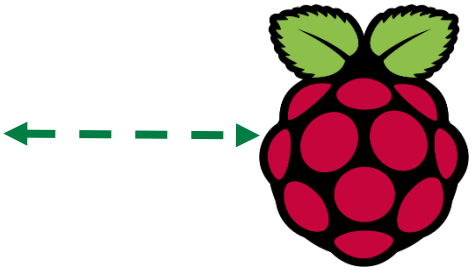
Technical Details

- Simulation of electrical diagram in real time
- Devices modelled in hardware components and interfaced to RTDS
- Communication with microgrid controller through Ethernet



Raspberry Pi transmits load and irradiance setpoints to RTDS model

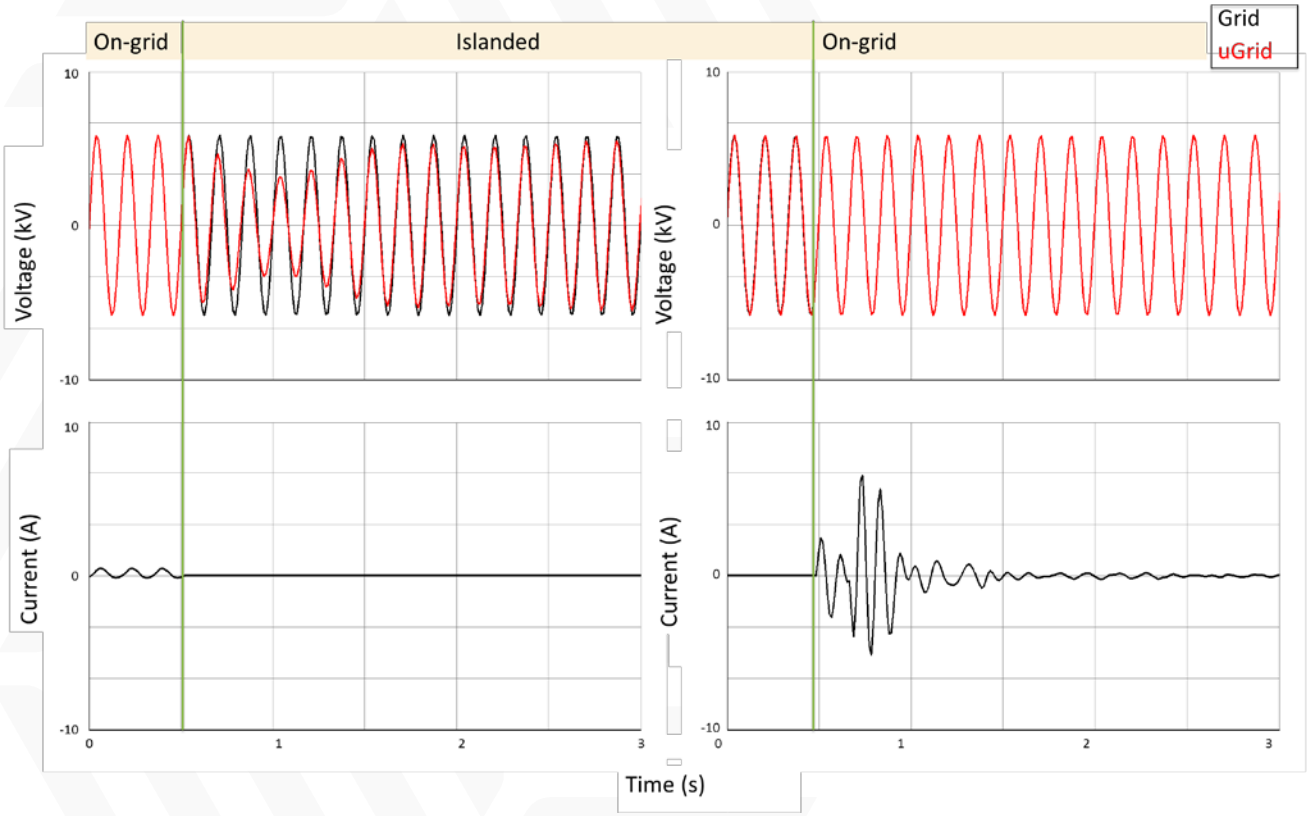
Reports measured load back to microgrid controller



Industrial Microgrid Analysis and Design for Energy Security and Resiliency

Technical Details

- Test results of islanding and resynchronization are provided to show the interactions among device level controllers and the master controller.



GRID MODERNIZATION INITIATIVE PEER REVIEW
GMLC 1.4.23 – Threat Detection and Response with Data Analytics

JAMIE VAN RANDWYK, LLNL

April 18-20, 2017

Sheraton Pentagon City – Arlington, VA

1.4.23 Threat Detection and Response with Data Analytics

High Level Summary

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Project Description

Develop advanced analytics on operational technology (OT) cyber data in order to detect complex cyber threats. Differentiate between cyber and non-cyber-caused incidents using available cyber data.

Value Proposition

- ✓ Analytics being developed will assist asset owners in triaging grid incidents
- ✓ Identifying incidents in a timely manner reduces outages and associated costs

Project Objectives

- ✓ Evaluate which sensor data is most valuable and could provide the biggest positive impact (in terms of grid resiliency/security) if an event is successfully detected.
- ✓ Develop analytics to identify emerging cyber incidents on the electric grid using this OT data identified in the previous objective.
- ✓ Attempt to differentiate cyber grid incidents from other grid hazard incidents, such as physical attacks, natural hazards, etc.

1.4.23 Threat Detection and Response with Data Analytics

Project Team

Project Participants and Roles

LLNL – AMI analytics, PI
LBNL – Inverter analytics, Plus one
INL – Physics-centric / cyber threat fusion and analysis
ORNL – Smart-grid outage data analytics
PNNL – Building automation system analytics
SNL – SEL Ethernet Gateway analytics
Electric Power Board (EPB) – Data, testing, and demo partner
Johnson Controls – Donating automation system hardware and software
Schweitzer Engineering Laboratories (SEL) – Data, testing, and demo partner

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
INL	240K	155K	55K
LBNL	240K	160K	170K
LLNL	210K	210K	210K
ORNL	35K	160K	255K
PNNL	35K	160K	255K
SNL	240K	155K	55K

1.4.23 Threat Detection and Response with Data Analytics

Relationship to Grid Modernization MYPP

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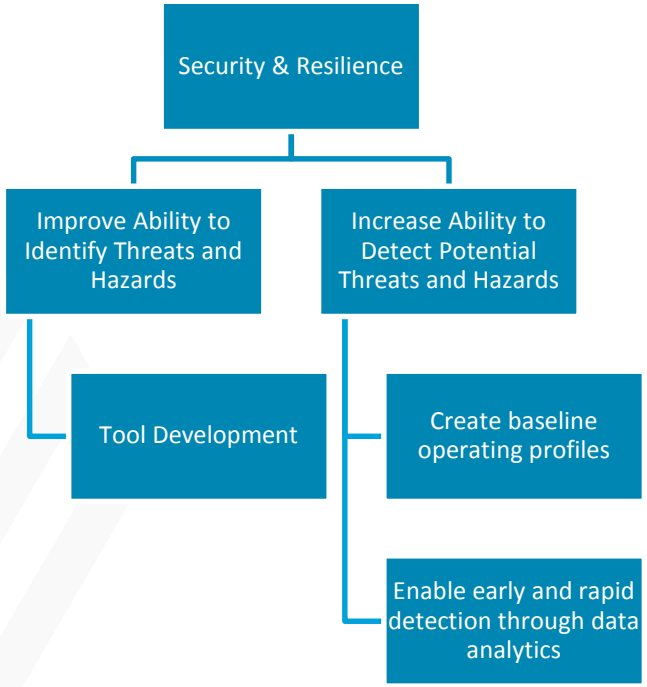
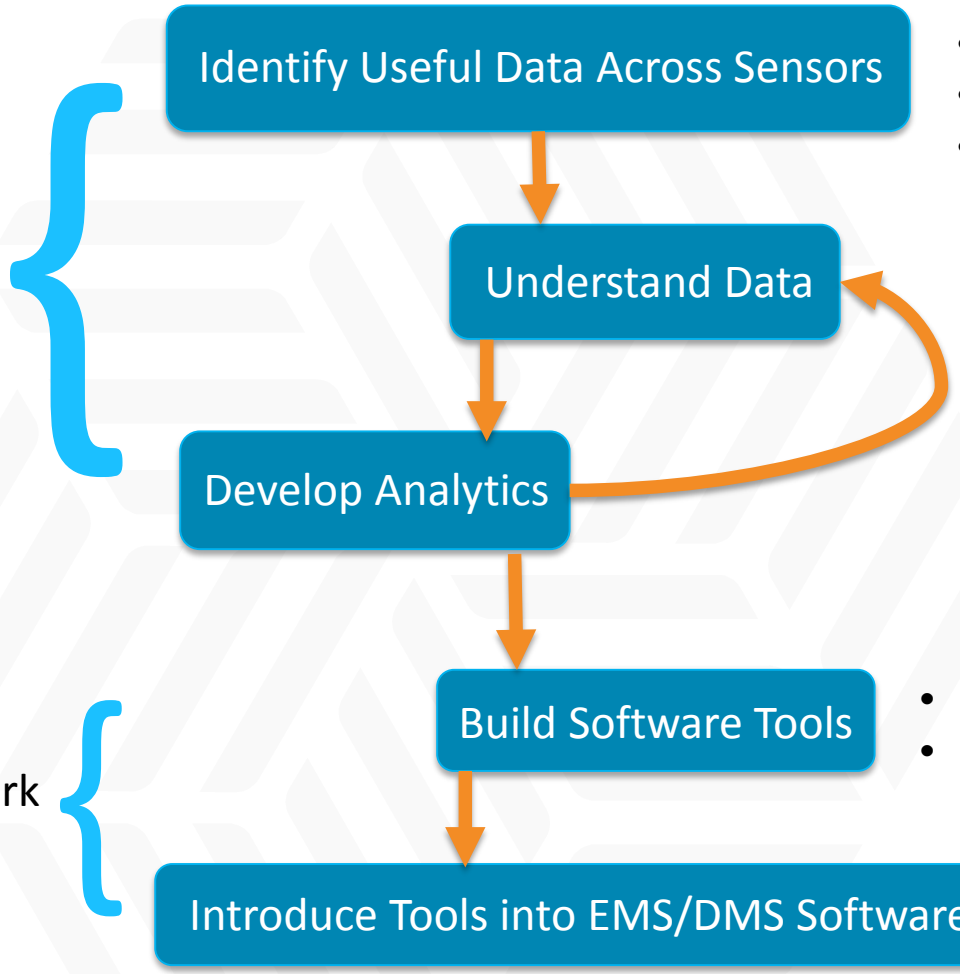
- This project addresses the Security & Resilience technical area by focusing on:
  - Improving the Ability to ***Identify*** Threats and Hazards
  - Increasing the Ability to ***Detect*** Potential Threats and Hazards
- We will conduct research and development on:
  - Data analytic tools to enhance early and rapid identification and detection of cyber threats
  - Baseline operating profiles as compared to off-normal profiles



1.4.23 Threat Detection and Response with Data Analytics

Approach



3-yr work scope

Future work phases

- Power inverters
- Battery storage systems
- µPMUs
- AMI

- Temporal characteristics
- Locality
- Volume

- Integrate data
- Write algorithms in prototype tools
- Early demonstrations
- Iterate

- Operationalize
- Demonstrate

- Identify industry partners

1.4.23 Threat Detection and Response with Data Analytics

Approach

- Develop analytics for DERs, substations, AMI, and microgrids that fuse physical and cyber information
  - Examine physical sensors (µPMUs, AMI, SEL-3620, and more traditional sensors) useful for detecting attacks
  - Simulate cyber attacks on battery storage systems, power inverters, and power meters
  - Evaluate sensed data and compare to predicted/expected values
  - Use statistical analysis and machine learning to identify cyber anomalies (as opposed to existing techniques that focus on operational and customer relations issues)
- Develop analytics for building automation systems (BAS)
  - Use PNNL Buildings-to-Grid testbed to study facility-level attacks that may have grid impact
- Develop analytics using outage data
  - Leverage normalized EAGLE-I outage data (Nov 2015 – Oct 2016) to identify outage outliers. These require further analysis and could indicate cyber attacks.

1.4.23 Threat Detection and Response with Data Analytics

Key Project Milestones

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Milestone (FY16-FY18)*	Status	Due Date
Establish MOU with industry collaborator (EPB) and identify sample data sets (related to NESCOR, EPB Smart Grid operations, etc.) for analysis. (ORNL)	Complete	10/1/16
Establish use case for evaluation of case studies. (INL)	Complete	4/1/17
Select set of AMI / smart grid hardware to use for experiments. Develop data agreement with partner. (LLNL)	In progress	7/1/17
Integrate SEL-3620 into selected NESCOR scenario. Identify physical and cyber events (features) in SEL-3620 available for monitoring. (SNL)	Complete	4/1/17
Organize subset of public outage data for specific distribution outages and transmission circuits for analysis. (ORNL)	Complete	4/1/17
Identify simulator requirements to perform attack-defense-mitigation study on PNNL testbed. (PNNL)	Complete	4/1/17
Understand, document, and ensure capture of device signaling protocols (LLNL)	Not started	10/1/17
Demonstrate analytics at asset owners (ALL)	Not started	4/1/19

*Selected milestones shown after year 1

1.4.23 Threat Detection and Response with Data Analytics

Accomplishments to Date

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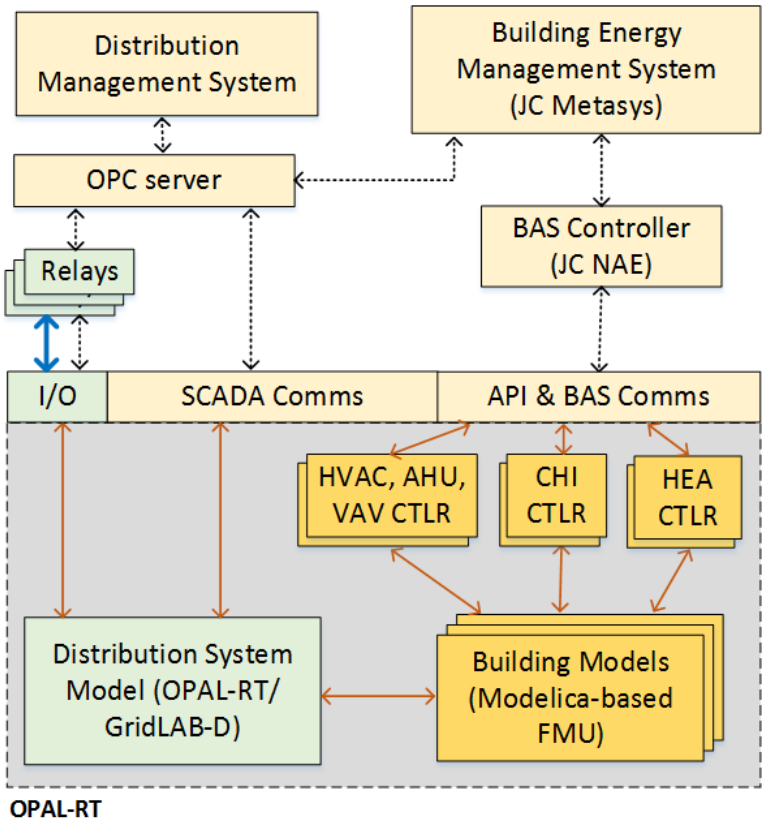
Milestone - Identify simulator requirements to perform attack-defense-mitigation study on PNNL testbed.

Status – Complete ✓

- **PNNL Buildings-to-Grid Testbed Components**
  - Buildings-to-Grid Simulator
    - Opal-RT for grid simulation
    - Modelica-based building thermal + electrical models integrated with grid model for composite B2G model
  - Building Automation
    - Johnson Controls (JC) Network Automation Engine for supervisory field control
    - JC Metasys for building energy management system
- **Current Status**
  - Proof-of-concept study – Attack on peak load shaving implemented through direct load control (NESCOR DR.3)
  - Targeting conference publication – Resilience Week 2017



PNNL Buildings-to-Grid Testbed Architecture

1.4.23 Threat Detection and Response with Data Analytics

Accomplishments to Date

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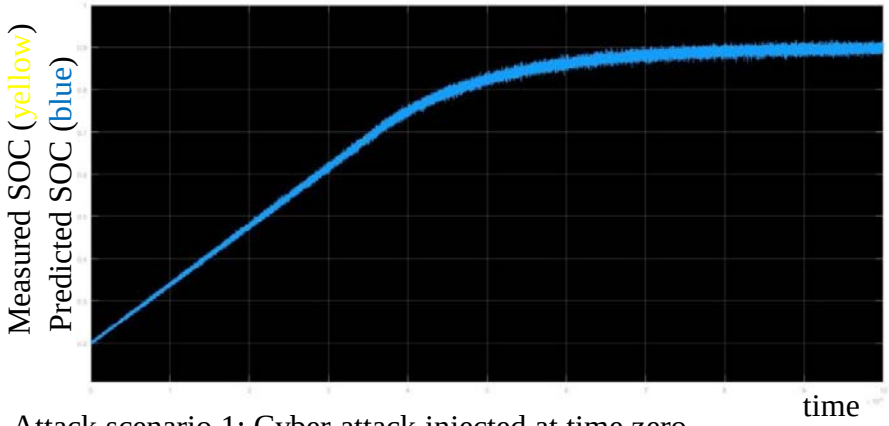
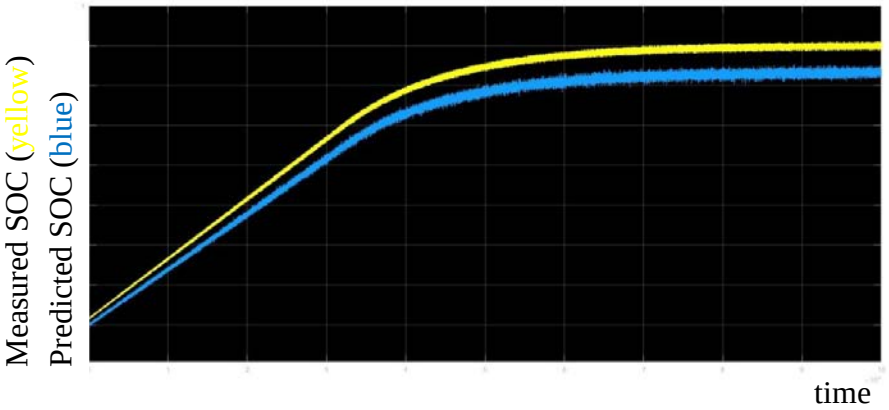
Attack scenario 1: No cyber attack

- Measured and predicted battery SOC statistically agree
- Statistical quality index stays below specified threshold, no statistical change declared, no physics-based anomaly alert issued



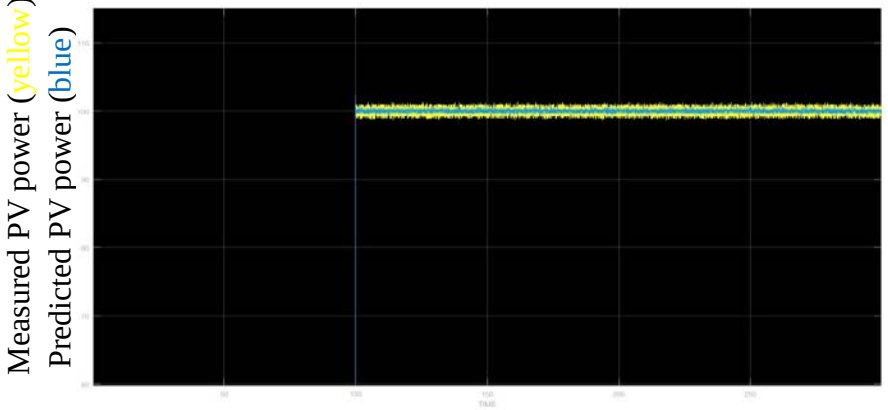
Attack scenario 1: Cyber attack injected at time zero

- Measured and predicted battery SOC statistically disagree
- Statistical quality index exceeds specified threshold, statistical changes are declared, and physics-based anomaly alerts are issued



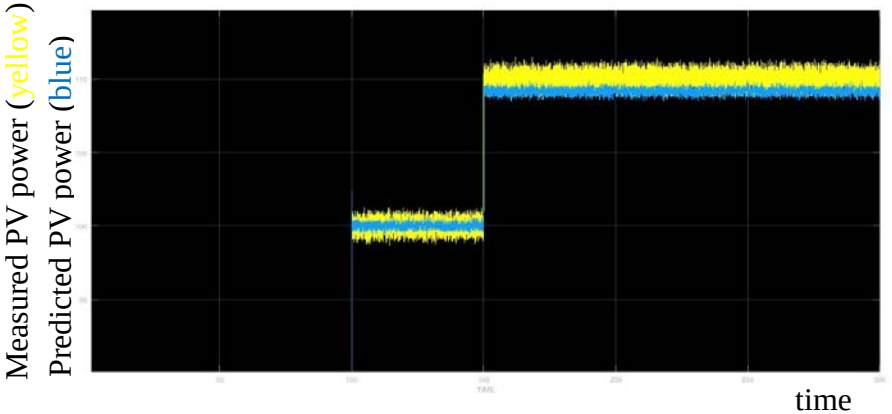
Attack scenario 2: No cyber attack

- Measured and predicted PV solar power statistically agree
- Statistical quality index remains under specified threshold, no statistical change declared, no physics-based anomaly alert issued



Attack scenario 2: Cyber attack injected at time 150

- Measured and predicted PV solar power statistically disagree
- Statistical quality index exceeds specified threshold, statistical changes are declared, physics-based anomaly alerts are issued



1.4.23 Threat Detection and Response with Data Analytics

Response to December 2016 Program Review

Recommendation	Response
Please clarify on how the six individual lab projects will be “fused” together at the annual peer review.	We’re following a multi-year research path to identify data sources, understand usefulness of that data, develop analytics, build software tools, and integrate those tools into industry grid monitoring software.
Please clarify how the results of this project will link to the work done in other projects across the Grid Modernization Lab Call.	Addressed in following slide

1.4.23 Threat Detection and Response with Data Analytics

Project Integration and Collaboration

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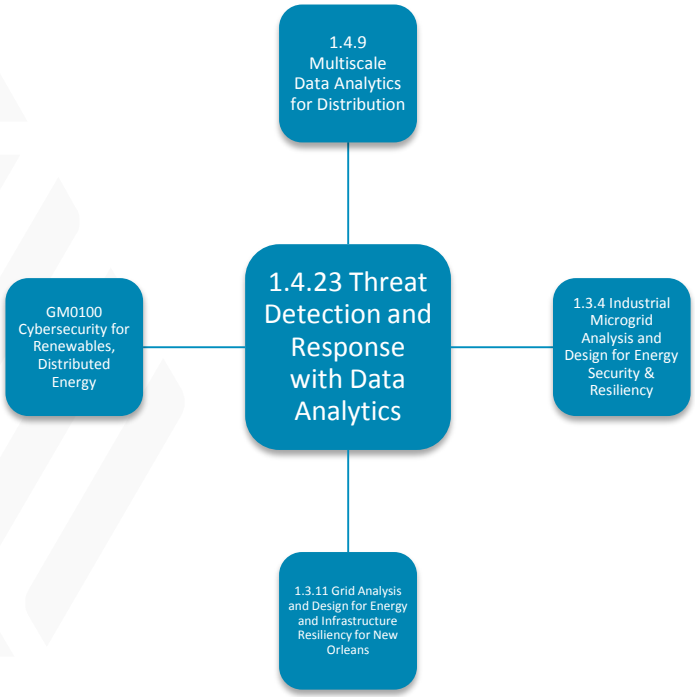
- 1.4.9 – Discussing partnering to share data and explore analytic relationships between µPMU and AMI sensor data
- 1.3.4 – Lesson learned: Process control SCADA could be as significant to grid resilience as grid operations SCADA
- 1.3.11 – Lesson learned: Cyber threat resilience has generally focused on transmission but distribution has significant resilience impact as well
- GM0100 – Future collaboration

Communications:

- Preparing submittal to Resilience Week 2017
- Presented project to DARPA, EPSA, DHS, WAPA and CAISO
- Seeking further industry partners for data sharing, demonstration, and commercialization



1.4.23 Threat Detection and Response with Data Analytics

Next Steps and Future Plans

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- Two more years! Much more to come.
- Future phases
  - ”Robustify” tools to fit into commercial software packages
  - Integrate analytic tools more tightly into a uniform suite that plugs into EMS/DMS

Lawrence Livermore National Laboratory

BERKELEY LAB

INL Idaho National Laboratory

OAK RIDGE National Laboratory

Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY
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Technical Details

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- Include technical backup here – no more than 5 slides