RESILIENT DISTRIBUTION SYSTEMS PROGRAM REVIEW

GMLC 1.5.06 - Designing Resilient Communities: A consequence-based approach for grid investment

BOBBY JEFFERS, ROBERT BRODERICK
SANDIA NATIONAL LABS

Oct 22-23, 2019

Washington, D.C.

Designing Resilient Communities

High-Level Project Summary

Project Description

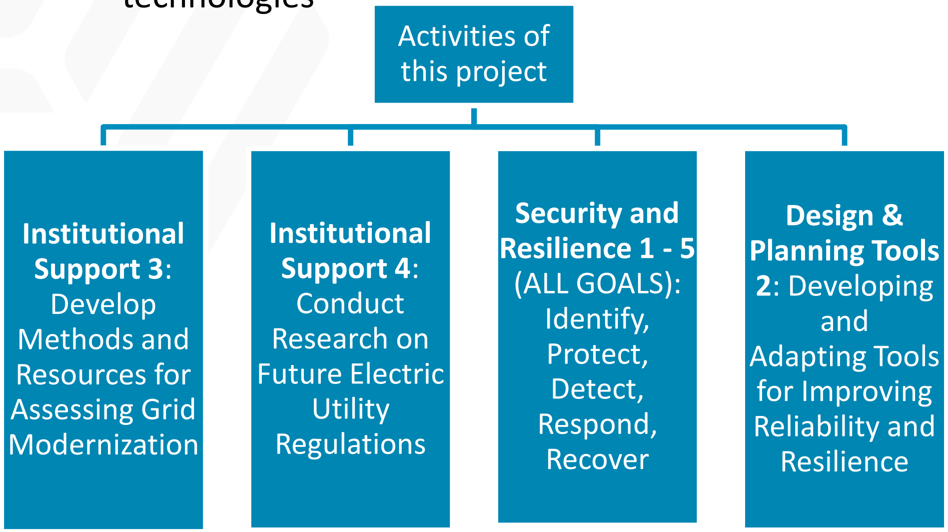
The high-level goal of this project is to demonstrate an actionable path toward designing resilient communities through consequence-based approaches to grid planning and investment and through field validation of technologies with utility partners to enable distributed and clean resources to improve community resilience.

Value Proposition

- ✓ Incorporating community resilience within electric utility investment planning
- ✓ Examining the impact of alternative regulatory frameworks and utility business models to incentivize resilience
- ✓ Demonstrating that a community resilience node can be implemented through clean, renewable technologies via inverter-dominated island protection and control

Project Objectives

- ✓ Form and hold national outreach meetings with a Stakeholder Advisory Group (SAG) that will inform the technical and policy solution space
- ✓ Design and implement (with two city/utility pairs) a widely-applicable framework that aligns grid investment planning with community resilience planning
- ✓ Design, implement, and field validate at a utility scale resilience nodes implemented predominately using clean distributed energy technologies



Designing Resilient Communities
Project Team

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project and Demonstration Partners

Sandia National Laboratories
100 RESILIENT CITIES (Pioneered by the Rockefeller Foundation)
CPS ENERGY
The University of Texas at San Antonio (UTSA)
City of San Antonio
nationalgrid
caño 3.7 (g-8 • enlace • fideicomiso)
Recinto Universitario de Mayagüez, Universidad de Puerto Rico
Synapse Energy Economics, Inc.
University at Buffalo, The State University of New York
NM STATE
CLEMSON UNIVERSITY

PROJECT FUNDING			
Lab	YR1 $	YR2$	YR3$
Sandia	1,500	1,500	1,500
100RC*	50	50	50
CPS Energy*	200	200	260
National Grid*	50	125	125
* = all cost share			

City + Utility Stakeholder Advisory Group

The City of Norfolk
Dominion Energy
City and County of Honolulu
Hawaiian Electric
City of Los Angeles
LA DWP
City of Boston
EVERSOURCE
City of New York
conEdison
City of Atlanta
Georgia Power

LVAT

BERKELEY LAB
Pacific Northwest National Laboratory

Additional Engaged Stakeholders

National Association of Regulatory Utility Commissioners
GE
US Army Corps of Engineers
City of New Orleans
SIEMENS
University of Pittsburgh

Designing Resilient Communities

Approach

1. **Development of national "Resilient Community Design" framework**
   - Deep interaction with Stakeholder Advisory Group (SAG)

2. **Demonstration, verification, and validation of the framework as applied to various community/utility constructs**
   - San Antonio and CPS Energy
   - National Grid and several NY communities
   - Smaller communities in Puerto Rico

3. **Investigation of alternative regulatory frameworks and utility business models**
   - Where is the line between resilience and "gold plating"?
   - How can utilities monetize consequence-focused resilience?

4. **Hardware demonstration of "resilience node" concept**
   - Focus on enabling inverter-dominated microgrids
   - Sandia providing adaptive protection and grid-forming inverter R&D

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Accomplishments – Task 1

Task 1 Accomplishments:

- Held 3 SAG meetings to date:
  - July 2018, Washington, D.C.
  - Jan 2019, Los Angeles, CA
  - July 2019, New York, NY
  - Scheduled: Jan 22-23, Washington, D.C.
  - SAG has agreed to keep these going for life of the project (July 2020 and Jan 2021)
- Released 3x SAG meeting "lessons learned" reports
- Built and maintained discussion/sharing forum for the SAG
- Developed new iteration of framework description based on feedback
- Social Burden metric development and modeling

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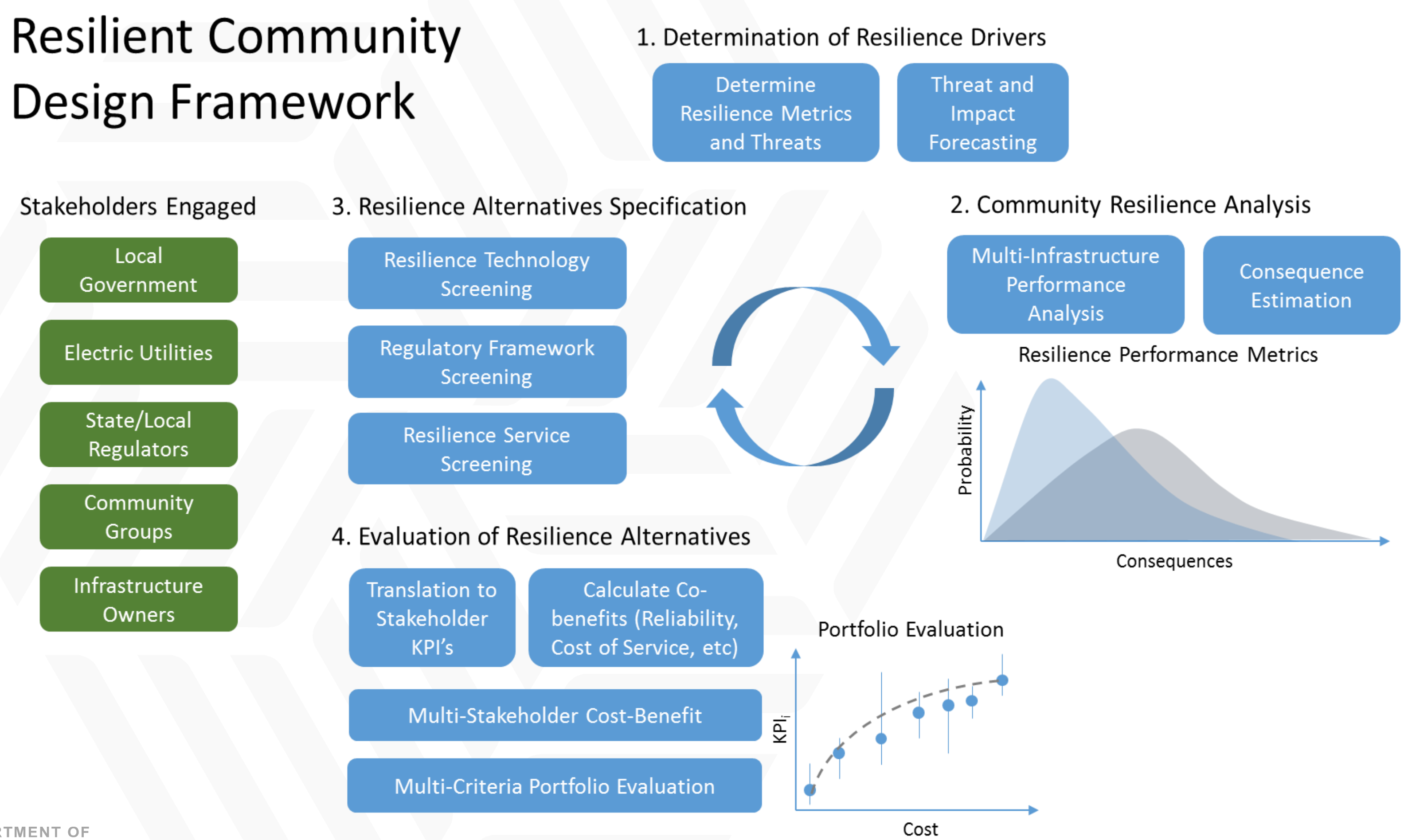
Accomplishments – Task 1

Previous Iteration of Resilient Community Design Framework:



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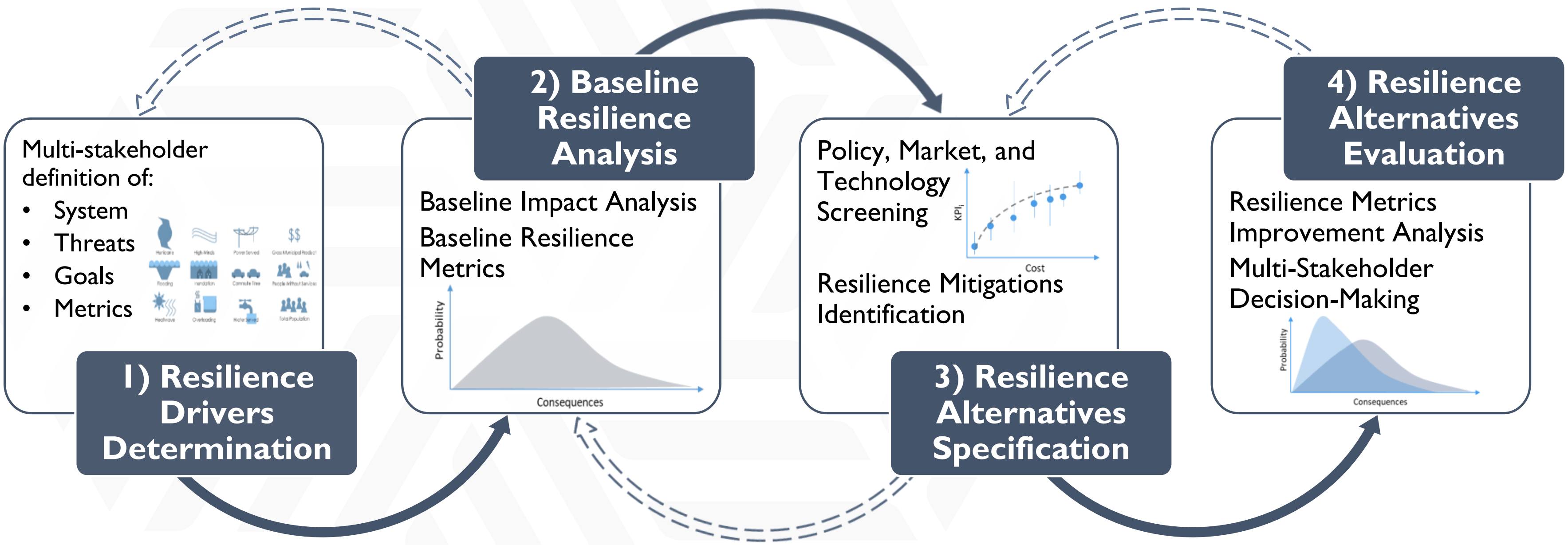
Accomplishments – Task 1

July 2019 Iteration of Resilient Community Design Framework:



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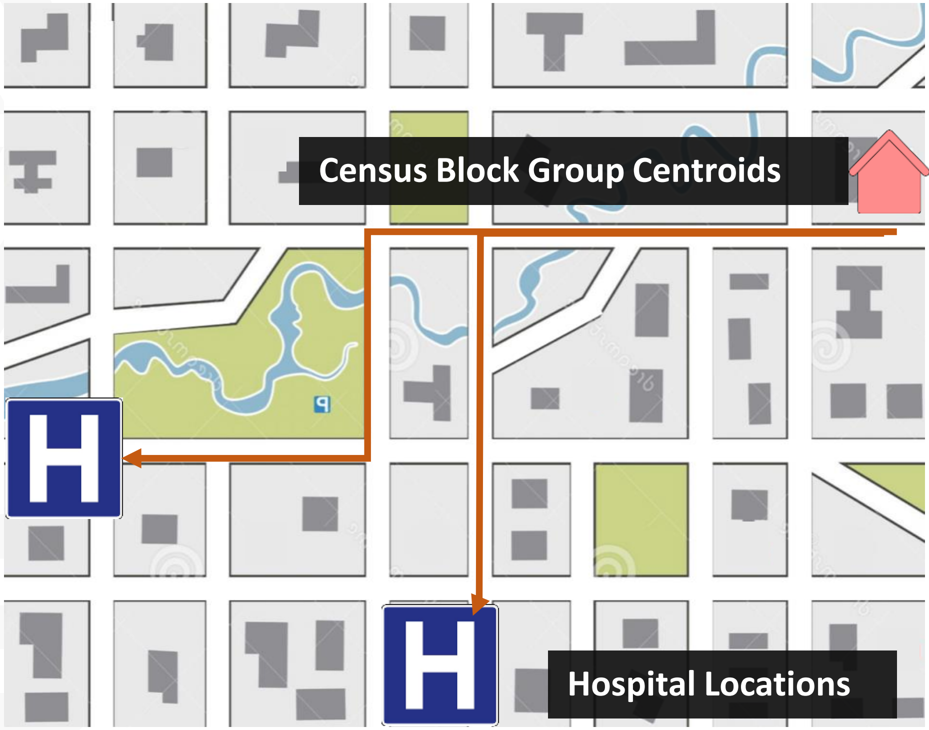
Accomplishments – Task 1

Social Burden Metric Development and Modeling (Peterson, Clark, et al.):

$$\text{Travel Cost} = [(T * \omega) + (D * v)]$$

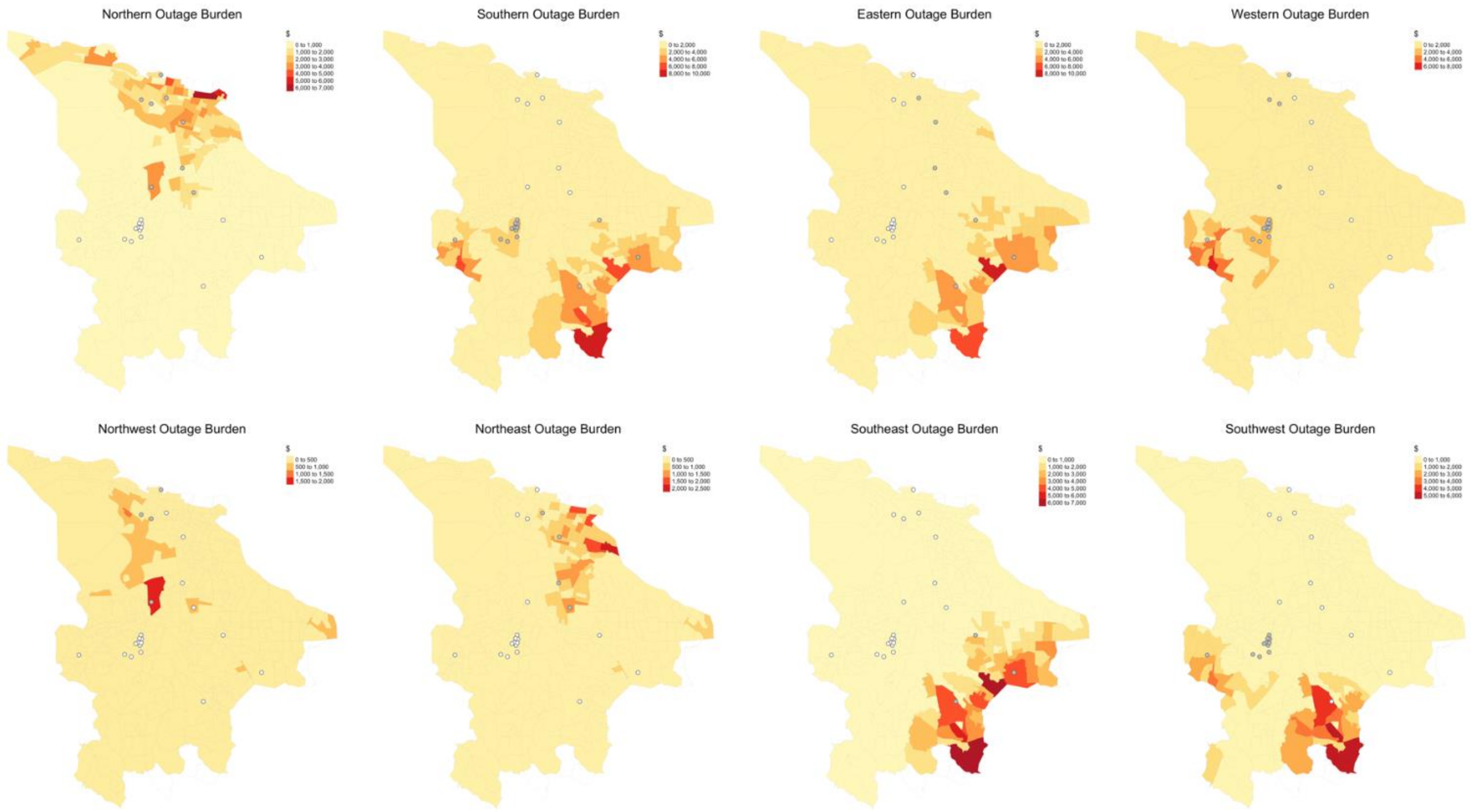
opportunity cost ($T * \omega$): *time * % wage rate*

direct travel cost ($D * v$): *distance * cost per mile*



Designing Resilient Communities
Accomplishments – Task 1

Social Burden Metric Development and Modeling (Peterson, Clark, et al.):



Accomplishments – Task 2

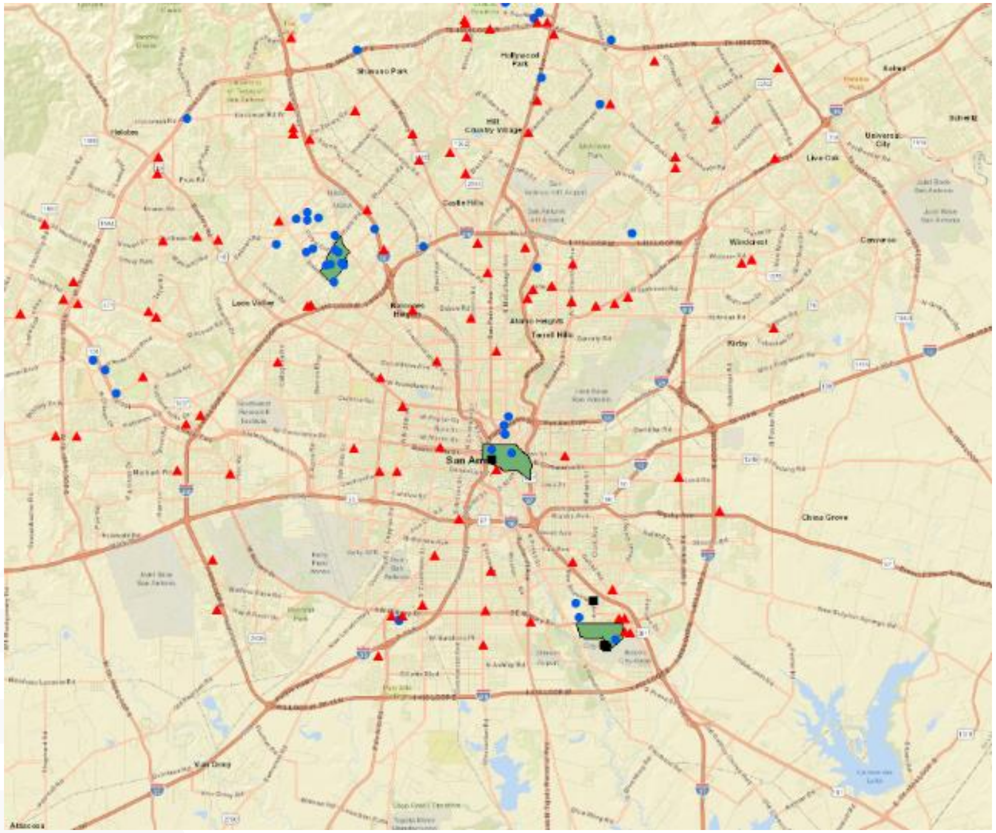
Task 2 Accomplishments:

- San Antonio
  - Finalized NDA's and began data sharing with City and CPS Energy
  - Scoped EV charging infrastructure effort with City and CPS Energy stakeholders
- Puerto Rico (recent addition)
  - In-person kickoff meeting in August 2019 with multiple stakeholders
  - Scoped resilience node siting and high-level design effort
- Upstate NY
  - Finalized NDA's and began data sharing with National Grid

San Antonio

Analysis will examine how decisions around fast charger infrastructure siting will impact grid and community resilience

- Co-beneficial design options to improve overall community resilience while enabling electrification
- Key considerations:
  - Evacuation patterns during large scale disruptions – increase in medium duty and heavy duty vehicles from outside the city
  - Forecast for EV adoption (residential as well as light/medium/heavy duty fleets), especially repair trucks, emergency vehicles, and public transportation
  - Shelter and community gathering locations, repair and emergency services vehicle staging locations

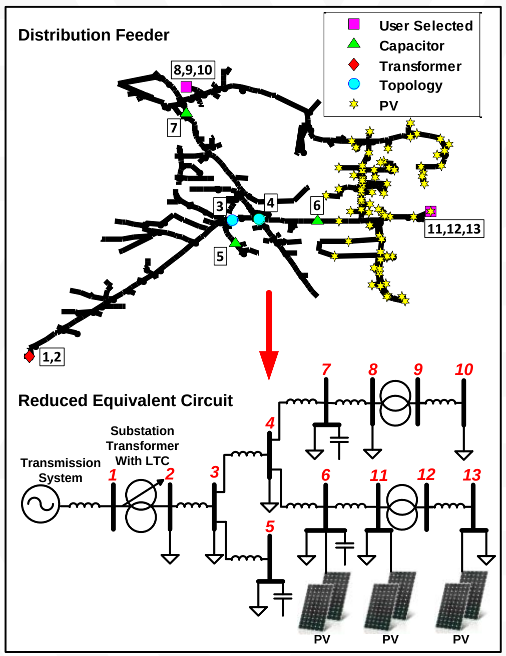


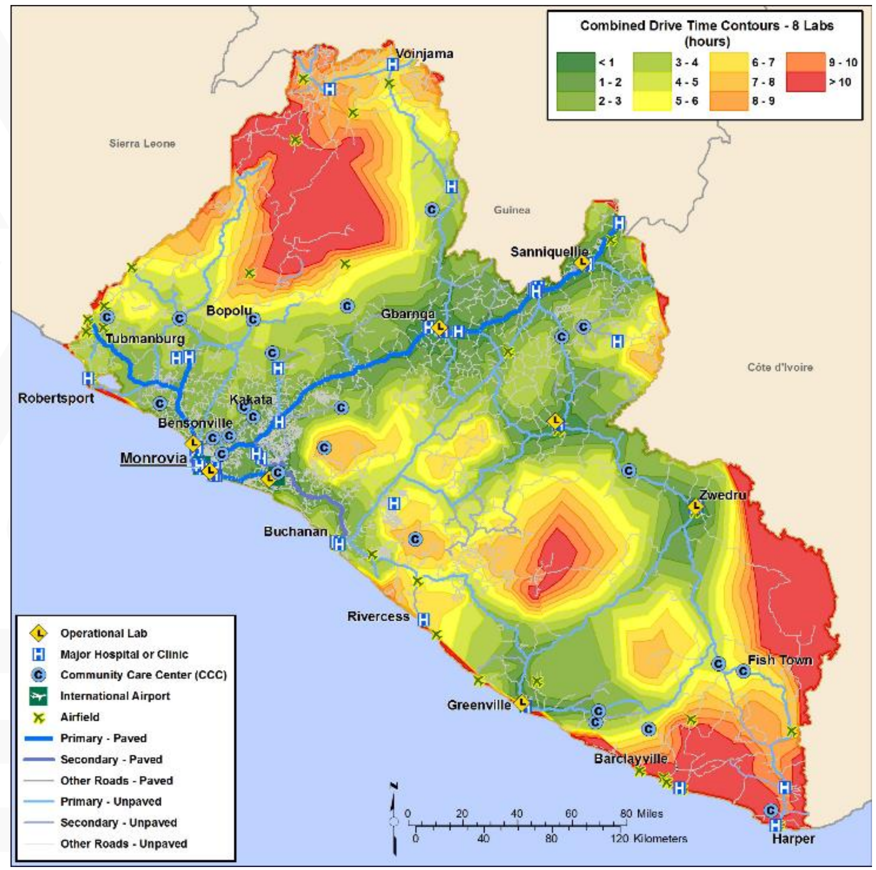
Grocery stores, EM, and Hospitals

San Antonio

Proposed modeling: coupled transportation system and grid QSTS

- Interaction between charging patterns, community resilience needs, and distribution system operations
- Data intensive!

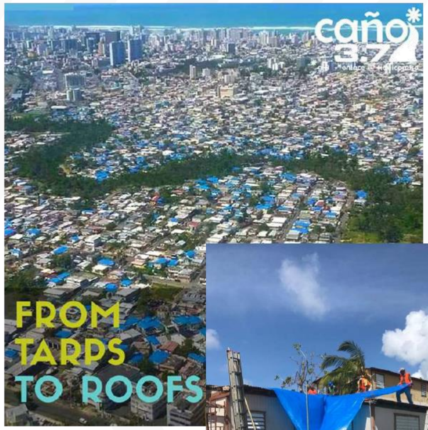




Puerto Rico

El Caño Martin Peña:

- 3.75 mile tidal channel
- Connects Bahia de San Juan to Laguna San Jose (critical connection for both systems)
- Citizens without sanitary sewer
- Citizens with blue tarp roofs
- Strong local governance
- Comprehensive dev. Plan
- EPA Urban Waters Partner



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Puerto Rico - El Caño communities

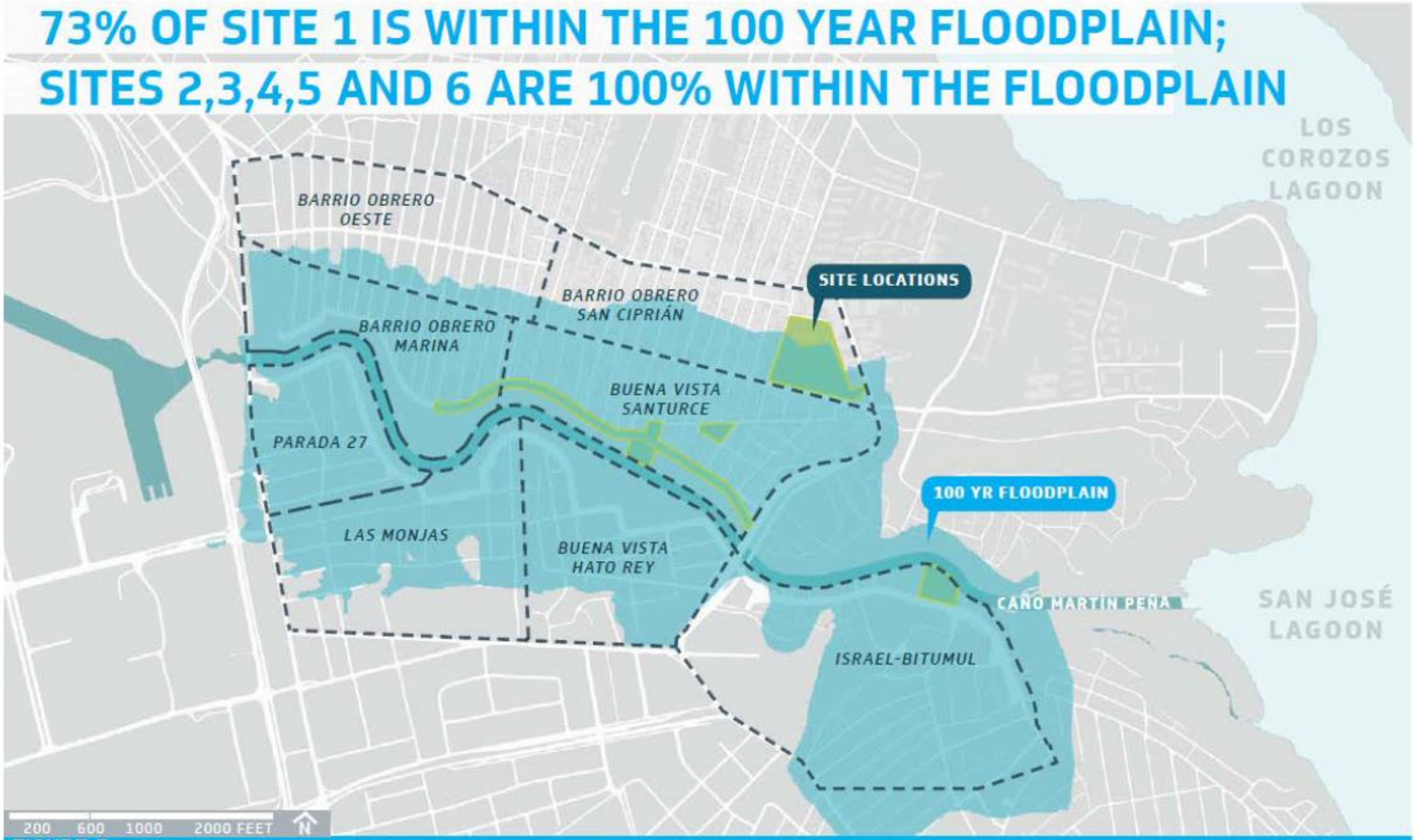


FIGURE 5 *Illustrating areas of the 100 year flood zones.*

Designing Resilient Communities
Accomplishments – Task 2

Puerto Rico - El Caño communities

August 2019 visit:
- Identified areas of development for the community
- Began determining critical needs during extreme flood/wind events
- Set groundwork for follow-on U-Buffalo survey
- Collected information for resilience node / microgrid analysis
- Determined opportunities for hardware demonstration

Upstate NY:

National Grid's current proposed resilience planning methodology

System: Distribution system for weather events

- Planning process:
  - A resiliency project shall be developed for 15 kV class feeders and stations that have one or more protection devices with a total seven year CHI (Customer Hours Interrupted) event outage value of greater than X CHI Outage Limits for major and minor storm events lasting greater than 12 hours
  - A station flood mitigation analysis shall be conducted for stations that are within the 100-year flood zone
  - Both criteria above are conditional upon a separate violation of a planning criteria element, i.e. load relief, reliability, asset condition etc.

Threats

- Weather impacts and trending towards longer duration and more frequent events
- Other company resiliency elements currently considered independently but not yet in an integrated fashion:
  - Physical attacks, Cyber security
  - Transmission: identification of weak topologies and high risk contingencies

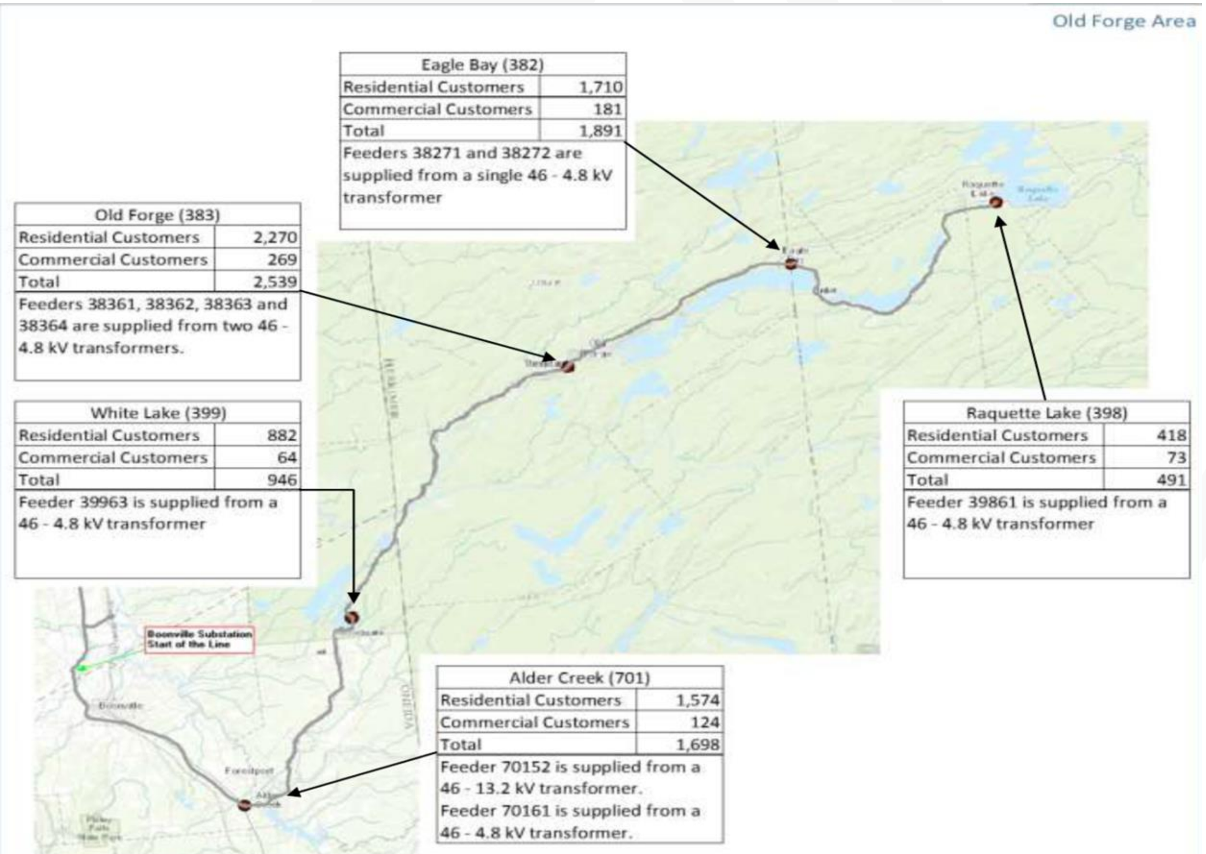
Goals

- Implement Resiliency projects to bring areas over CHI metric back within criteria Solutions to consider the following time periods (IEEE PES-TR65): Manage disruption, Quickly respond, Fully recover and adapt
- Improve customer experience and satisfy increasing expectations

Metrics

- CHI metric confirmed via historical lookback and probabilistic simulations
- Benefit Cost Analysis

Old Forge Example: (reliability -> resilience)



- $4 Million cost impact to customers per year over past 5 years for outages
- Old Forge customers were interrupted an average of 7.97 times per year for an average of 20.11 hours per year over the last five years – 10 times more than the NiMo average interruption duration of 2.52 hours

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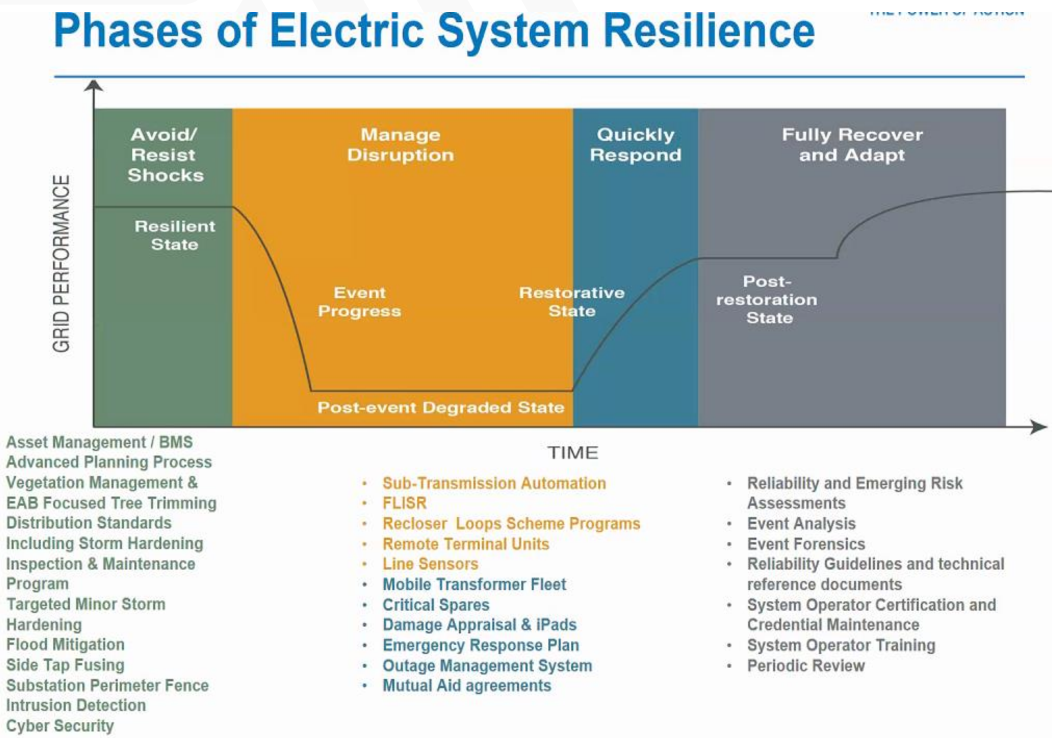
Old Forge Example: (reliability -> resilience)

Stakeholders Engaged

- Several departments in National Grid:
  - Planning,
  - Grid Modernization Solutions
  - Economic Analysis
  - Reliability
  - NWA
- Microgrid developers
- NYPSC



Tools/Resources Used

- Under development but would likely use the following tools:
- DOE ICE Tool
- REMII tool
- Cost Book
- CYME (RAM)
- DERCAM – Microgrids
- Benefit Cost NY Handbook

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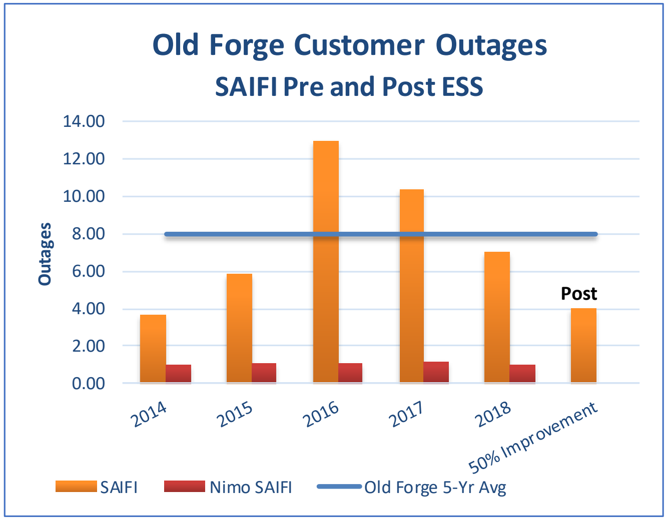
National Grid Demonstration Site (2 options)

- Old Forge Site (Planned) New York
  - NON-WIRES ALTERNATIVE SOLUTIONS FOR OLD FORGE
  - Options being considered: Energy Storage, CHP, load control and run of river hydro.
  - Goal: Support investigation of adaptive protection schemes for inverter only islanding.



- North Troy Site in New England (Installed)
  - 2MW/3MWh storage project that is currently being installed in North Troy that is a demonstration project primarily for load support.
  - Considering whether to test the ability of this storage unit to form an island (small 1-1.5 MW island by transferring several feeders off the station bus).
  - They key questions we need to address are the protection coordination considering low short cct level i.e. 5-6X nominal inverter current. This higher than normal due to the unique type of inverter NG is using.
  - Goal: become comfortable with an inverter validated model and associated simulations before conducting any physical tests.

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Task 3 Accomplishments:

- Five interrelated work efforts in collaboration with team partners Synapse Energy Economics

	Description	Synapse Work Products
Task 3.1	Outreach, verification and gap analysis	Report on landscape of community and utility experiences
Task 3.2	Resilient communities design framework demonstration	Resilience performance metrics matrix and report
Task 3.3	Alternative regulatory frameworks and utility service design	Benefit cost analysis (BCA) report and tool
		Report on microgrids
		Report on alternative regulatory frameworks

Designing Resilient Communities

Accomplishments – Task 3.1

Perspectives from 6 diverse community/utility pairs interested in resilience

Primary criteria

- utility regulatory structure
  - muni, co-op, vertically-integrated IOU, deregulated IOU
- geography
  - eastern, western, central
- threats
  - intentional and natural

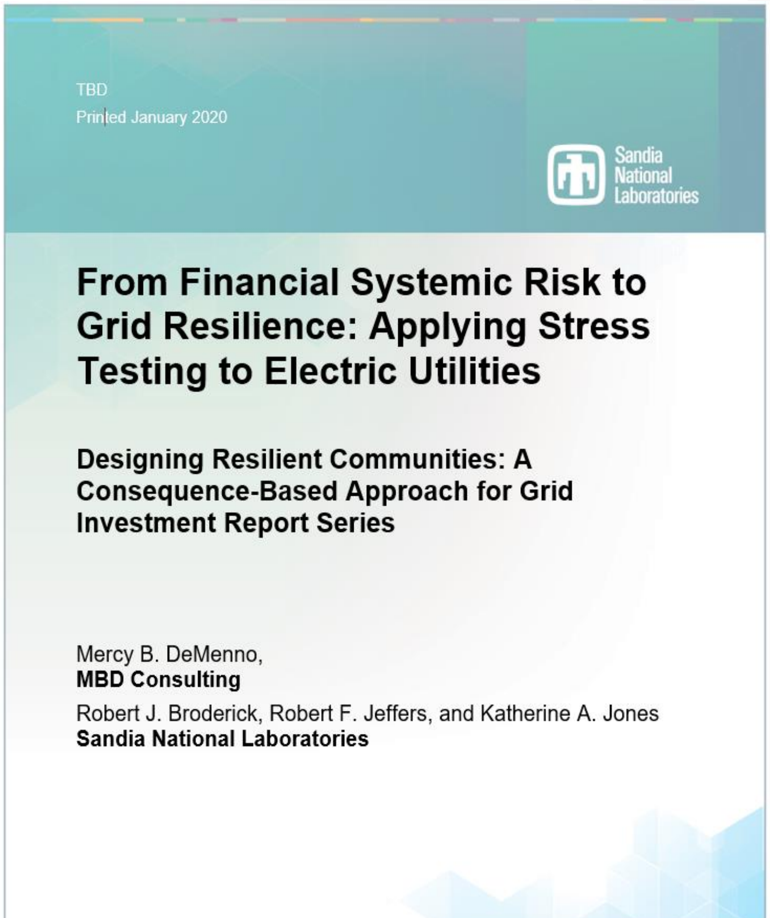
Secondary criteria

- community size
  - small, medium, large
- involved in the stakeholder working group
  - yes or no

Designing Resilient Communities

Accomplishments – Task 3.1

Manuscript on stress testing to address systemic grid risks



TBD
Printed January 2020

Sandia National Laboratories

From Financial Systemic Risk to Grid Resilience: Applying Stress Testing to Electric Utilities

Designing Resilient Communities: A Consequence-Based Approach for Grid Investment Report Series

Mercy B. DeMenno,
MBD Consulting

Robert J. Broderick, Robert F. Jeffers, and Katherine A. Jones
Sandia National Laboratories

- To be presented at annual meeting of the Society for Risk Analysis, Dec. 2019
- To be published as SRA Journal Article in 2020: "From Financial Systemic Risk to Grid Resilience: Applying Stress Testing to Electric Utilities"

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Accomplishments – Task 3.2

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Menu of performance metrics for utilities and communities for tracking, reporting and establishing goals

Metric Categories and Examples

1. Reliability

- Hardiness
- Automation
- Redundancy
- Criticality

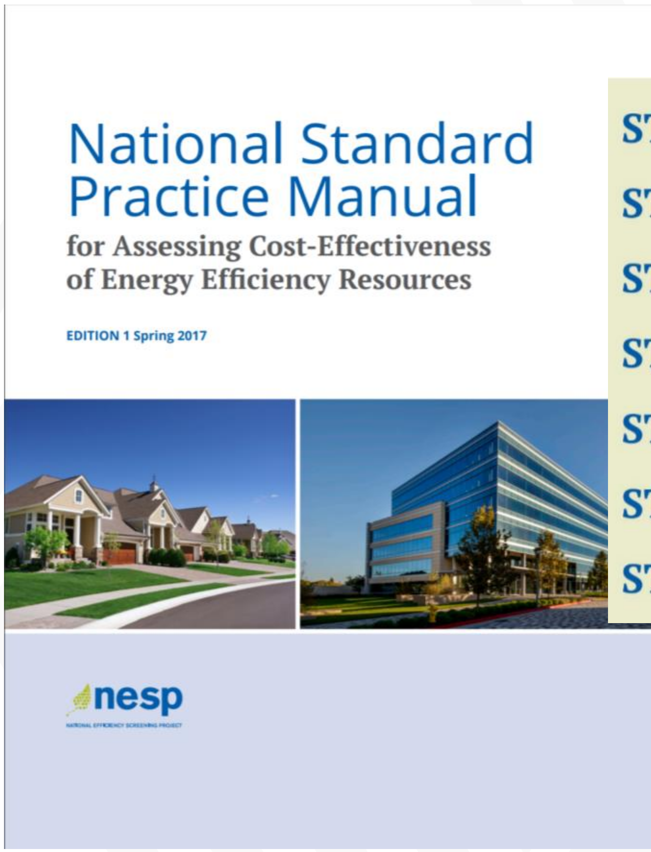
2. Flexibility

- Responsiveness
- Diversity
- Mobility

3. Safety/Security

- Energy Burden
- Damages
- Injury/Loss of Life

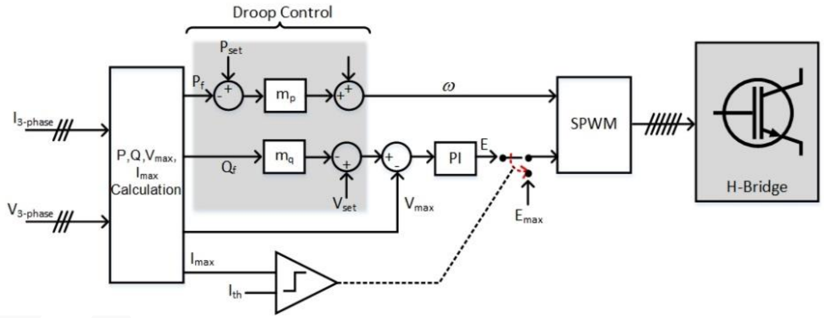
Adapting and evolving energy efficiency benefit cost analysis approaches for resilience

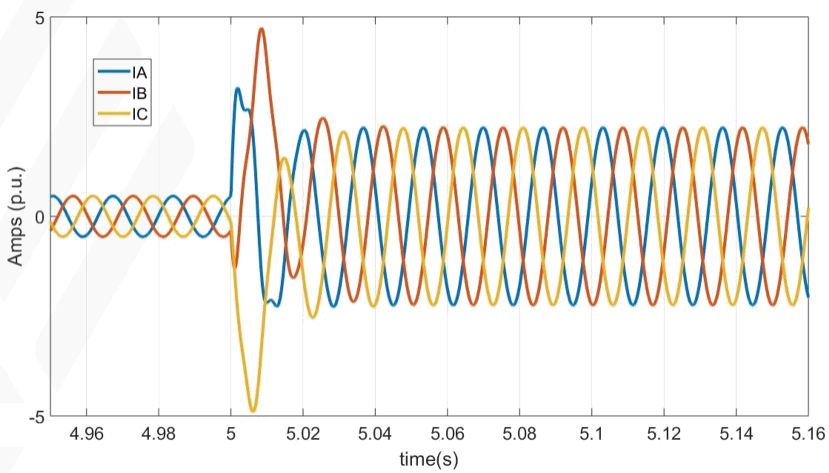


- **STEP 1** Identify and articulate the jurisdiction's applicable policy goals.
- **STEP 2** Include all the utility system costs and benefits.
- **STEP 3** Decide which non-utility impacts to include in the test, based on applicable policy goals.
- **STEP 4** Ensure that the test is symmetrical in considering both costs and benefits.
- **STEP 5** Ensure the analysis is forward looking and incremental.
- **STEP 6** Develop methodologies to account for all relevant impacts, including hard to quantify impacts.
- **STEP 7** Ensure transparency in presenting the inputs and results of the cost-effectiveness test.

Task 4 Accomplishments:

- Modeling of grid forming inverters for protection studies
  - Collaboration with New Mexico State University
- Installing, testing, and validating designs using PHIL
  - Demonstration at DETL
- Adaptive protection design
  - Collaboration with Clemson University
  - Demonstration at DETL



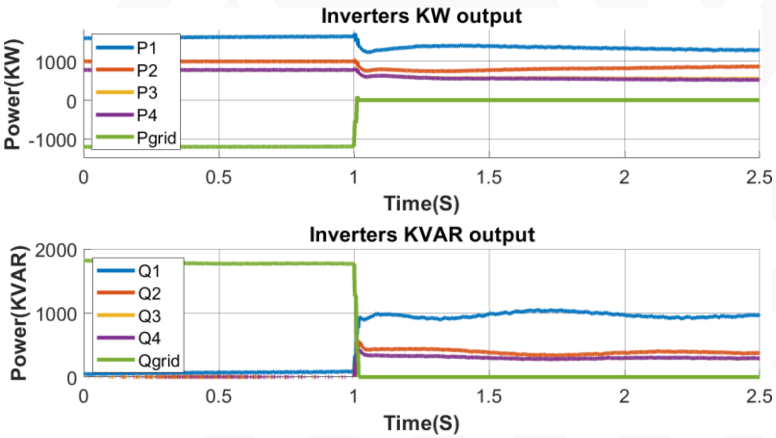


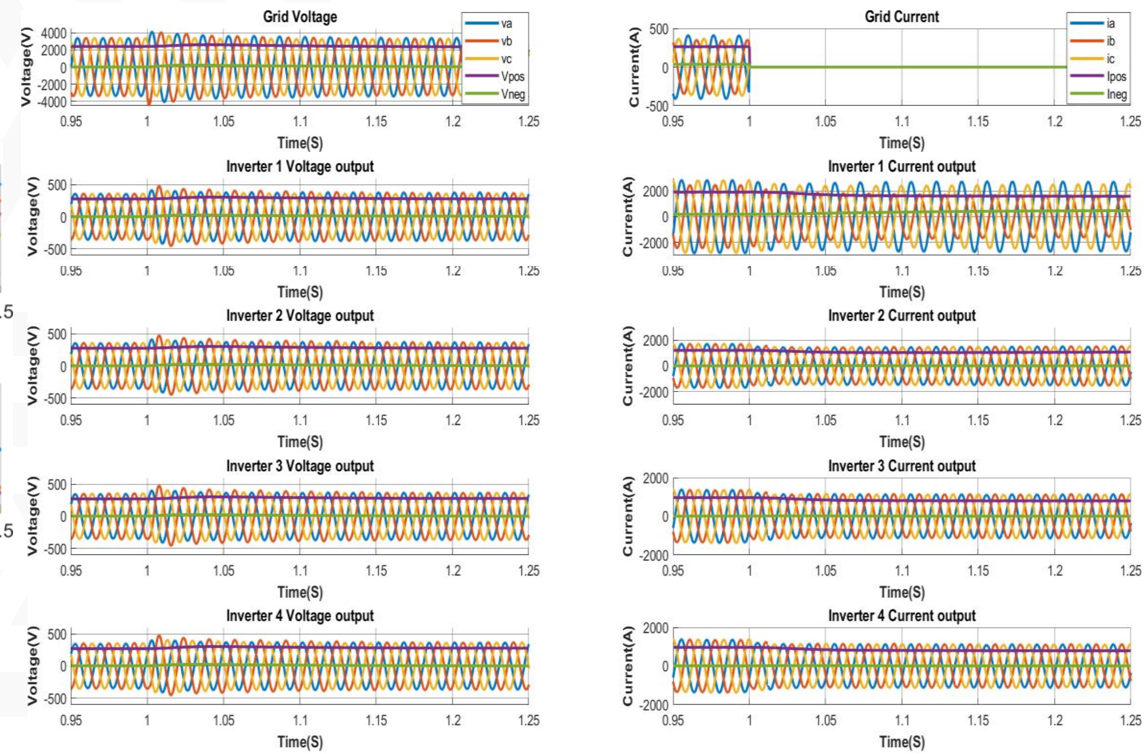
Publications:

- J. Hernandez-Alvidrez, A. Summers, M. J. Reno, J. Flicker, N. Pragallapati "**Simulation of Grid-Forming Inverters Dynamic Models using a Power Hardware-in-the-Loop Testbed**"," IEEE Photovoltaic Specialists Conference (PVSC), 2019.
- N. S. Gurule, J. Hernandez-Alvidrez, M. J. Reno, A. Summers, S. Gonzalez, and J. Flicker, "**Grid-forming Inverter Experimental Testing of Fault Current Contributions**," IEEE Photovoltaic Specialists Conference (PVSC), 2019.
- P. H. Gadde and S. Brahma, "**Realistic Microgrid Test Bed for Protection and Resiliency Studies**," North American Power Symposium (NAPS), 2019.

Modeling of grid forming inverters during transition from grid connected to islanded mode

- System is islanded at t=1s. Grid is disconnected and the grid-forming inverter (Inverter 1) provides the frequency reference, reactive power, and negative and zero sequence necessary to maintain the grid





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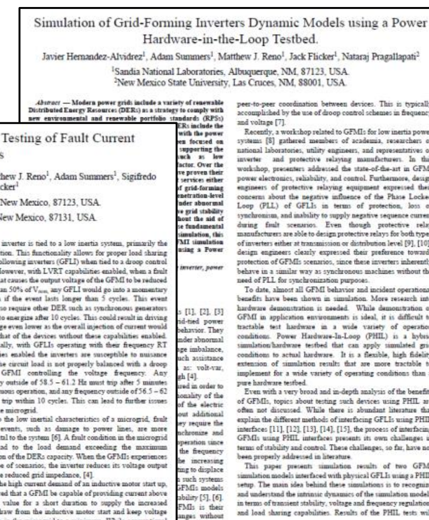
Installing, testing, and validating designs using PHIL

Demonstration of resilient nodes based on the framework.

Initial demonstration using PHIL at Sandia DETL

- Grid-forming inverters (GFMI) have been integrated into DETL for demonstration
- This collection of single-phase and three-phase, solar GFMI and battery GFMI, and different vendors allows us to demonstrate different systems and test how various inverter designs will perform:
  - OutBack Power
  - Schneider Electric
  - Princeton Power Systems
  - SMA
  - ABB



Simulation of Grid-Forming Inverters Dynamic Models using a Power Hardware-in-the-Loop Testbed.

Javier Hernandez-Alvidrez[1], Adam Summers[1], Matthew J. Reno[1], Jack Flicker[1], Nataraj Pragallapati[2]

[1]Sandia National Laboratories, Albuquerque, NM, 87123, USA.
[2]New Mexico State University, Las Cruces, NM, 88001, USA.

Abstract — Modern power grids include a variety of renewable Distributed Energy Resources (DERs) as a strategy to comply with new environmental and renewable portfolio standards (RPSs) ...

... peer-to-peer coordination between devices. This is typically accomplished by the use of droop control schemes in frequency and voltage [7].

Recently, a workshop related to GFMIs for low inertia power systems [8] gathered members of academia, researchers of national laboratories, utility engineers, and representatives of ...

Grid-forming Inverter Experimental Testing of Fault Current Contributions

Nicholas Sonny Gurule[1,2], Javier Hernandez-Alvidrez[1], Matthew J. Reno[1], Adam Summers[1], Sigifredo Gonzalez[1], and Jack Flicker[1]

[1] Sandia National Laboratories, Albuquerque, New Mexico, 87123, USA.
[2] University of New Mexico, Albuquerque, New Mexico, 87131, USA.

Abstract — Historically, photovoltaic inverters have been grid-following controlled, but with increasing penetrations of inverter-based generation on the grid, grid-forming inverters (GFMI) are gaining interest. GFMIs can also be used in microgrids that require the ability to interact and operate with the grid (grid-tied), or to operate autonomously (islanded) while supplying their ...

... when an inverter is tied to a low inertia system, primarily the FW function. This functionality allows for proper load sharing of grid-following inverters (GFLI) when tied to a droop control GFMI. However, with LVRT capabilities enabled, when a fault occurs that causes the output voltage of the GFMI to be reduced ...

I. INTRODUCTION

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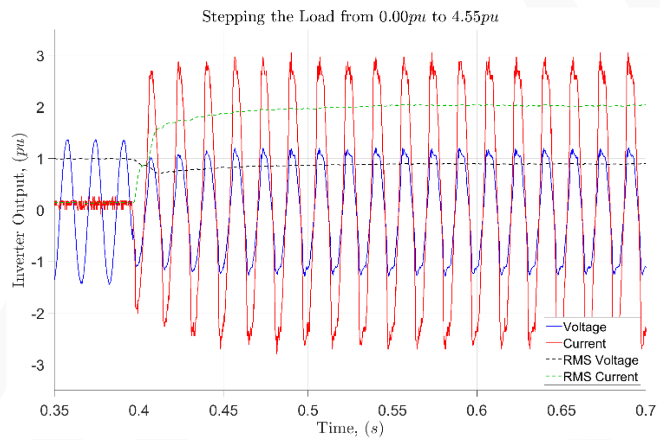
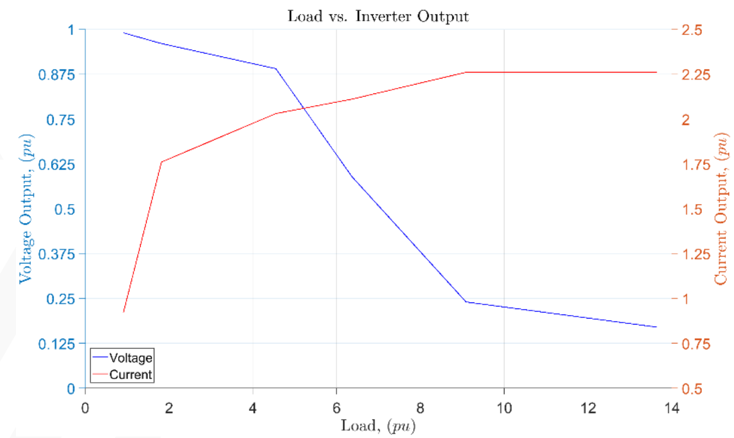
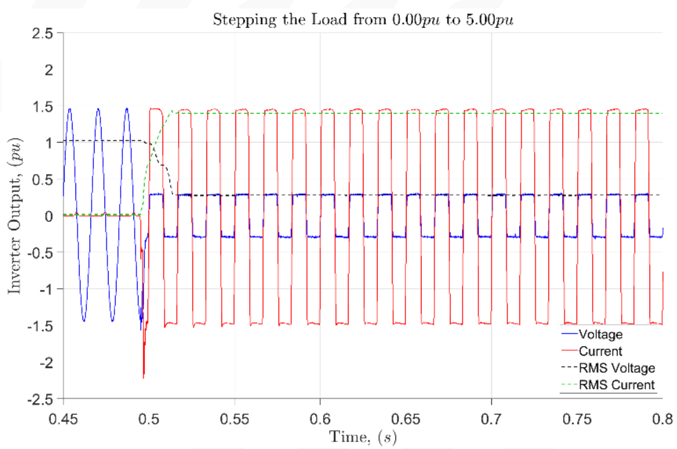
Testing and characterization of grid forming inverters at lab scale

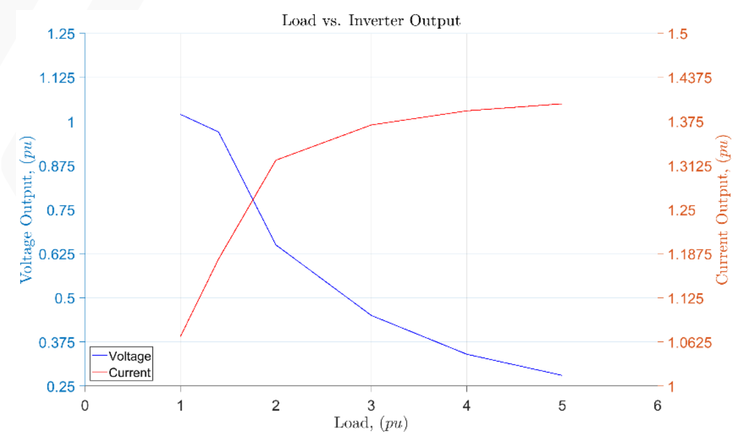


Inverter 1



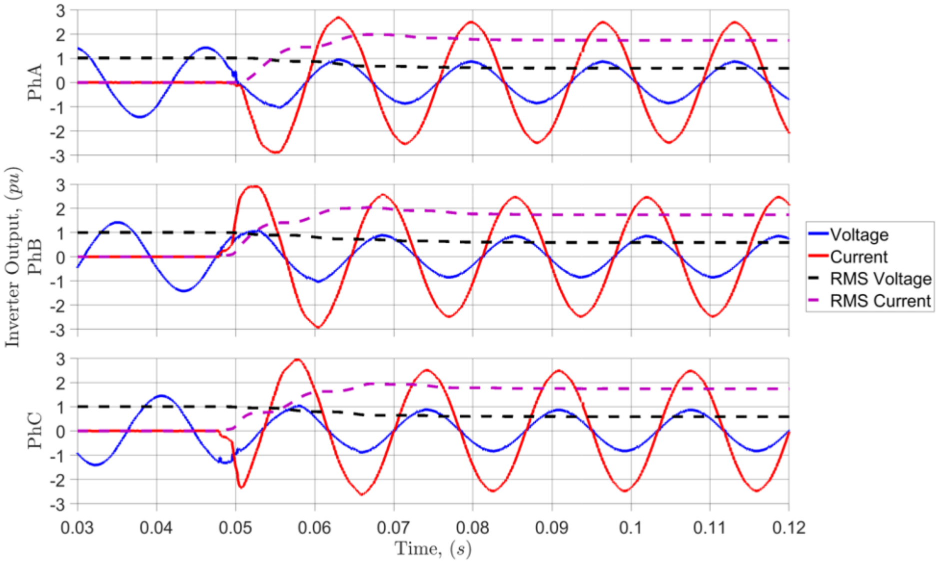


Inverter 2

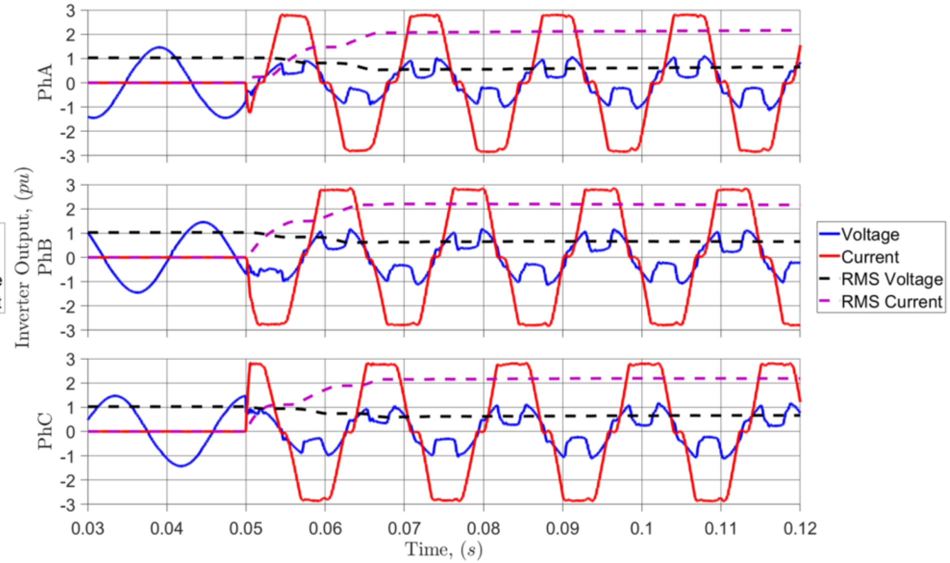


3-Phase Grid Forming Inverters Fault Testing:

- 3 pu load applied
- Up to 2 pu fault current for <1 cycle
- ~1.74 pu fault current steady state



- 4.3 pu load applied
- >2 pu fault current steady state
- Results demonstrate vendor uses hysteresis control method for limiting the current

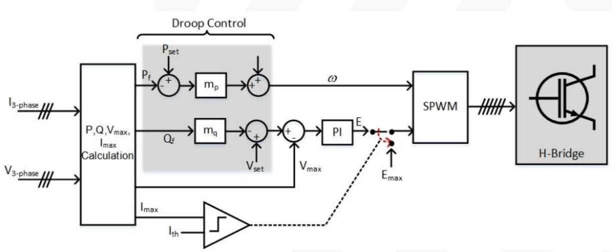


Unlike grid following inverters, grid-forming inverters do not control the current directly since they are regulating voltage and frequency. In order to protect their thermal limits, they must regulate current during fault conditions. The current limiting control is done differently by different manufacturers.

We have implemented a collection of the common current limiting methods to perform protection studies for resilient nodes with inverters

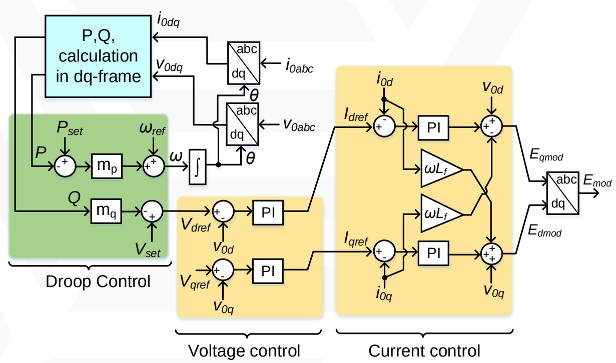
Control Mode Transition

Limit the amplitude of the Sinusoidal Pulse Width Modulation (SPWM) by switching to current control above a certain threshold



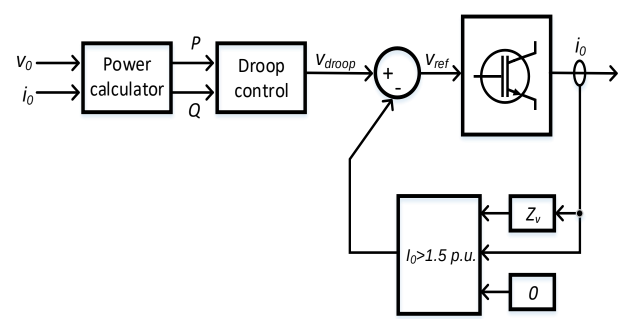
dq-Current Control

Similar to dq-current control for grid-following inverters with cross coupling terms

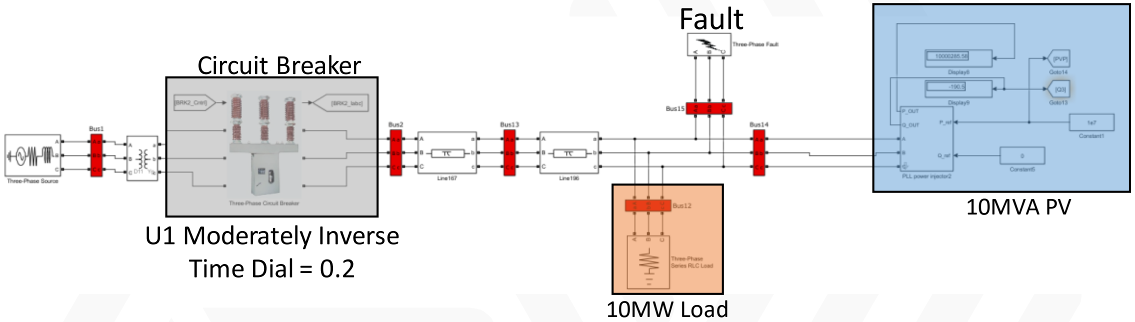


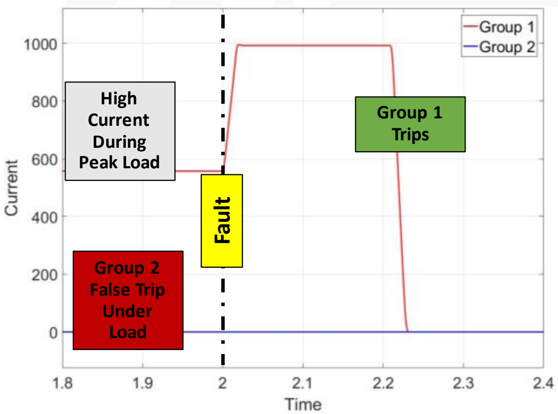
Virtual Impedance

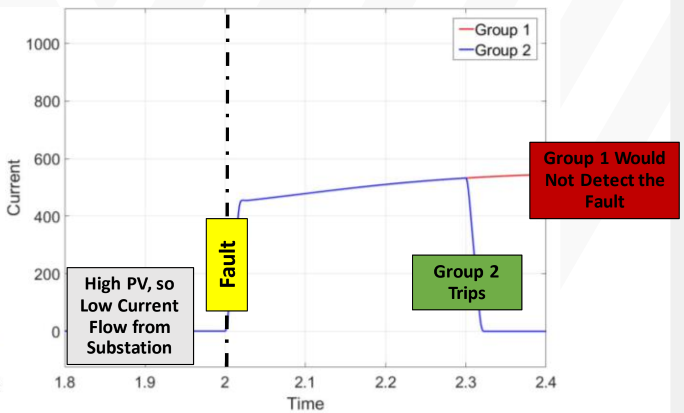
Indirect method based on modifying the reference voltage with a virtual impedance if the output current is above a threshold

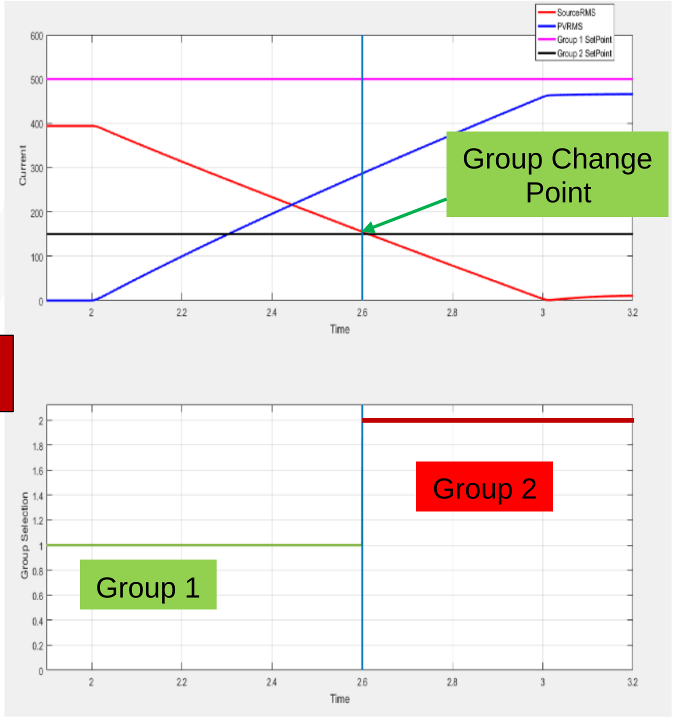


Designing adaptive protection schemes for inverter-dominated microgrids









Awarded plus-up to “full project” status on Aug 16, 2018

GMLC Designing Resilient Communities	Yr0				Yr1				Yr2				Yr3			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
1 Outreach, Verification, Gap Analysis																
1.1 SAG Formation and Hosting																
1.2 Verification and Gap Analysis																
1.3 Tech Outreach and Framework																
2 Framework Demonstration																
2.1 Threat ident and metric spec																
2.2 Baseline resilience analysis																
2.3 Portfolio specification																
2.4 Additional benefits																
2.5 Resilience cost/benefit analysis																
3 Reg Frameworks and Service Design																
3.1 Alternative policy collection																
3.2 Alternative policy evaluation																
4 Field Validation of Resil Nodes																
4.1 Dyn models under faults																
4.2 Resilient protection lab scale																
4.3 Cyber resil protection test																
4.4 Utility scale demo non-protection																
4.5 Utility scale demo with protection																

Designing Resilient Communities
Discussion and Coordination

- We are seeing value from integrating cities in the resilience discussion. How can we better integrate this viewpoint?
  - Many loosely connected offices within city gov't
  - Cities can be one financing opportunity
  - Smaller communities also have a role (See: Puerto Rico and NY examples)
- What are the strengths and challenges of the resilience node concept?
  - Does it necessitate inverter-dominated or DC microgrids?
  - Protection remains a challenge – what are some other challenges?
- We are seeing aggressive fossil-free goals. How can we achieve these goals and maintain resilience?
  - Great can be enemy of the good: cities "skipping" district thermal systems
  - Better balance between sustainability, efficiency, and resilience?
- How far should we go "beyond grid?"
  - Transportation systems
  - Emergency response
  - Buildings
  - Communications
  - Other…

THANK YOU!

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