Resiliency & Microgrids Working Group

Value of Resiliency – 4 Pillar Methodology:
Pillar 2 Mitigation Measure Assessment and
presentations by Sandia and Lawrence Berkeley National Labs

Resiliency and Microgrids Team, Energy Division

June 3, 2021

California Public
Utilities Commission

WebEx and Call-In Information

Join by Computer:

https://cpuc.webex.com/cpuc/onstage/g.php?MTID=e09727a93a478e5c8cc6c50fbfd11e0c8

Event Password: RMWG (case sensitive)

Meeting Number: 187 471 0648

Join by Phone:

- Please register using WebEx link to view phone number.

(Staff recommends using your computer's audio if possible.)

Notes:

- Today's presentations are available in the meeting invite (follow link above) and will be available shortly after the meeting on https://www.cpuc.ca.gov/resiliencyandmicrogrids.

- The meeting presentations by Sandia and Lawrence Berkeley National Labs will be recorded. There will not be meeting minutes.

WebEx Logistics

- All attendees are muted on entry by default.
- Questions can be asked verbally during Q&A segments using the "raise hand" function.
  - The host will unmute you during Q&A portions [and you will have a maximum of 2 minutes to ask your question].
  - Please lower your hand after you've asked your question by clicking on the "raise hand" again.
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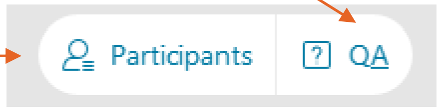
WebEx Tip

Access the written Q&A panel here

1. Click here to access the attendee list to raise and lower your hand.



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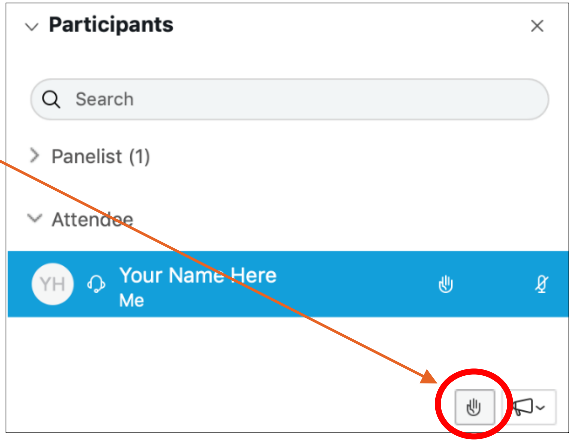

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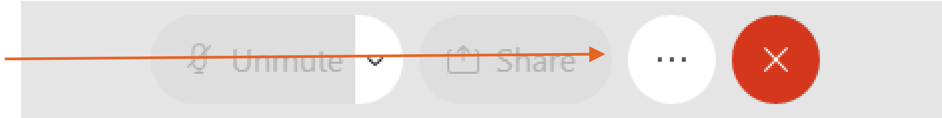
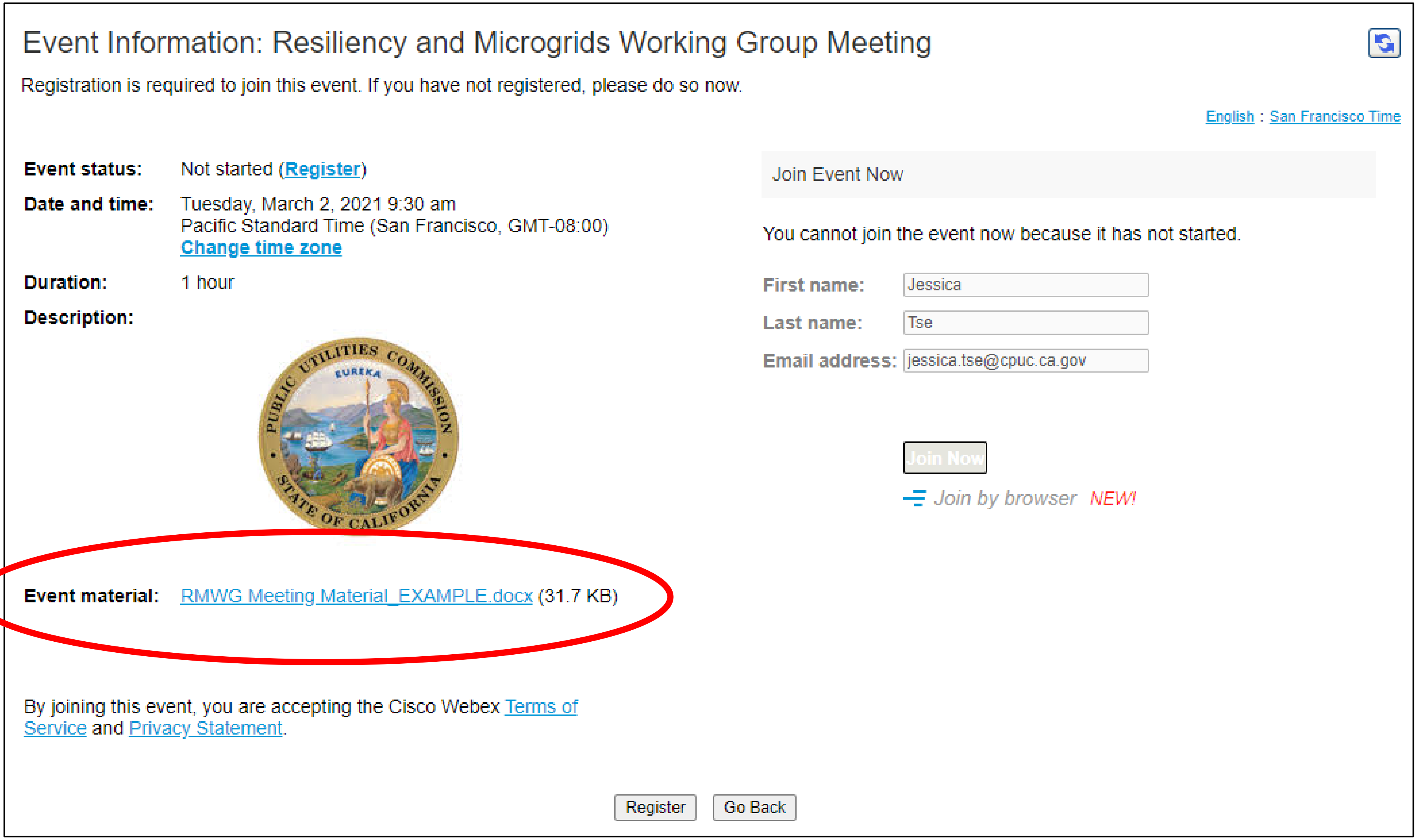


WebEx Event Materials


Event Information: Resiliency and Microgrids Working Group Meeting

Registration is required to join this event. If you have not registered, please do so now.

English : San Francisco Time

Event status: Not started (Register)

Date and time: Tuesday, March 2, 2021 9:30 am
Pacific Standard Time (San Francisco, GMT-08:00)
Change time zone

Duration: 1 hour

Description:

Event material: RMWG Meeting Material_EXAMPLE.docx (31.7 KB)

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Preliminary Resiliency & Microgrids Working Group Schedule

<table>
<tr><th>Month</th><th colspan="4">Resiliency and Microgrids Working Group Topics</th></tr>
<tr><td>February</td><td rowspan="3">Standby Charges</td><td rowspan="4">Multi-Property Microgrid Tariff</td><td></td><td></td></tr>
<tr><td>March</td><td></td><td></td></tr>
<tr><td>April</td><td></td><td></td></tr>
<tr><td>May</td><td></td><td rowspan="4">Value of Resiliency</td><td></td></tr>
<tr><td>June</td><td></td><td></td><td></td></tr>
<tr><td>July</td><td></td><td></td><td></td></tr>
<tr><td>August</td><td></td><td></td><td rowspan="4">Microgrid Interconnection</td></tr>
<tr><td>September</td><td></td><td></td><td></td></tr>
<tr><td>October</td><td></td><td></td><td></td></tr>
<tr><td>November</td><td rowspan="4">Customer-Facing Microgrid Tariff Revisit</td><td></td><td></td></tr>
<tr><td>December</td><td></td><td></td><td></td></tr>
<tr><td>January</td><td></td><td></td><td></td></tr>
<tr><td>February</td><td></td><td></td><td></td></tr>
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Value of Resiliency: Working group participants to discuss resiliency valuation through an all-hazard approach to disruptions and mitigations by examining metrics, methodologies, and policy applications.

Value of Resiliency – 4 Pillar Methodology
Pillar 2: Mitigation Measure Assessment and presentations by Sandia and Lawrence Berkeley National Labs

June 3, 2021

Rosanne Ratkiewich

Julian Enis

Resiliency and Microgrid Team

California Public Utilities Commission

Agenda

I. Introduction (CPUC Staff) 2:00 – 2:05p

- WebEx logistics, agenda review

II. Value of Resiliency: Pillar 2–Mitigation Measure Assessment 2:05 – 2:35p

- What protection options do we have?
- What does the best job at protecting the most?
- What does it cost?

Q&A

III. Resiliency and Reliability Optimization tools 2:35 -- 3:55p

- Brian Pierre – Sandia Labs

  Q&A
- Miguel Heleno – Lawrence Berkeley Labs

  Q&A

IV. Closing Remarks, Adjourn 3:55 – 4:00p

- Provide information on the next meeting

The Problem to Solve: How can we optimize grid investments to maximize resiliency?

4 Pillars of Resiliency Valuation

I. **Baseline Assessment**
   I. What do we want to protect and where is it?
   II. What threatens it?
   III. How well are we doing now to protect it?

II. **Mitigation Measure Assessment**
   II. What protection options do we have?
   III. What does the best job at protecting the most?
   IV. What does it cost?

III. **Resiliency Scorecard** – scoring resiliency configuration characteristics

IV. **Resiliency Response Assessment (post-disruption or modeling)** –
   II. How well did the investments do in reaching resiliency targets?
   III. Did the investments reduce impacts on the community?

Hazards to Mitigate with Resiliency Measures

Nevada County
Local Hazard Mitigation Plan Update
August 2017

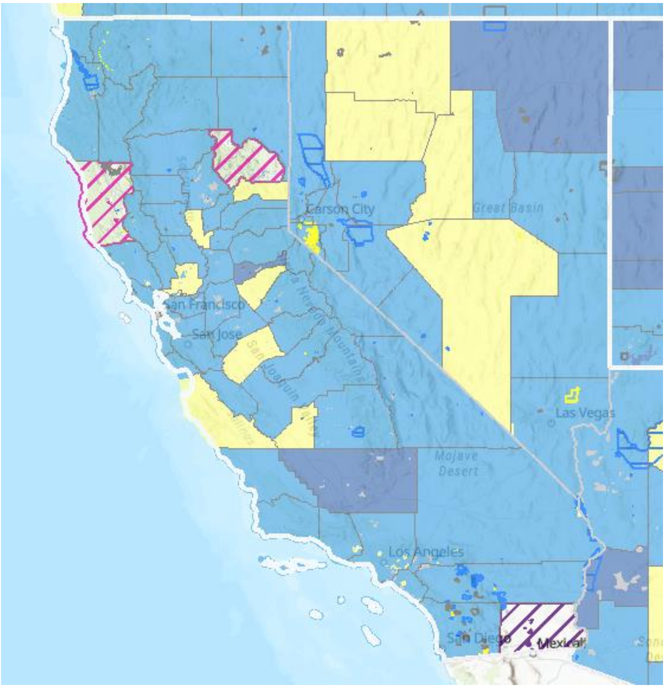
United Nations Office for Disaster Risk Reduction (UNDRR) – **Disaster Resilience Scorecard for Cities - Quick Risk Estimator tool:** provides a framework for local governments to assess hazards unique to their area.

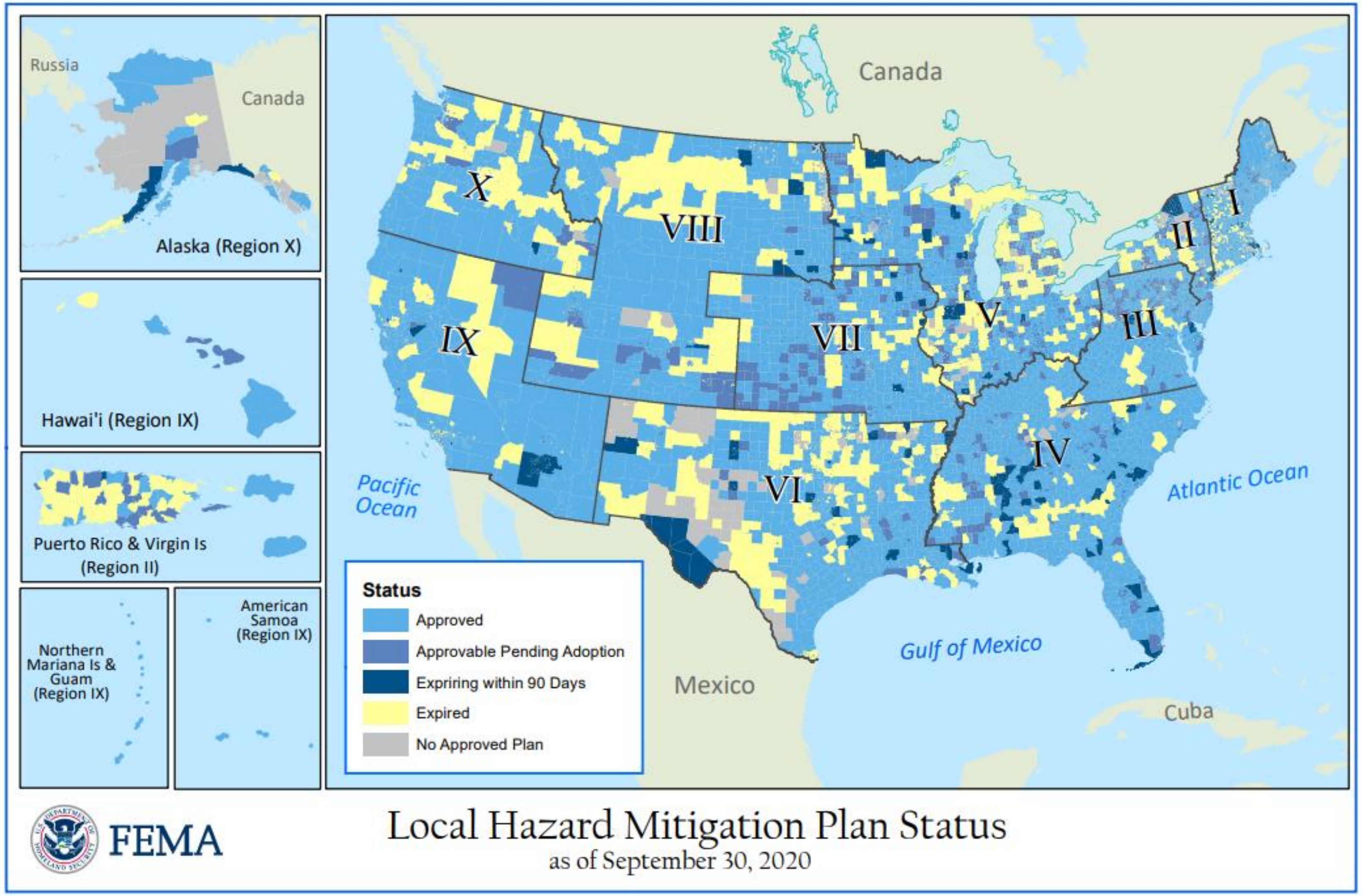
Table ES-2 Nevada County Hazard Identification Assessment

Hazard	Geographic Extent	Probability of Future Occurrences	Magnitude/ Severity	Significance	Climate Change Influence
Ag Hazards: Severe Weather/Insect Pests	Significant	Highly Likely	Critical	High	High
Avalanche	Limited	Highly likely	Negligible	Low	Low
Climate Change	Extensive	Likely	Critical	Medium	High
Dam Failure	Significant	Occasional	Catastrophic	High	Low
Drought and Water Shortage	Extensive	Likely/ Occasional	Critical	Medium	Low
Earthquake	Extensive	Unlikely	Critical	Medium	Low
Flood: 100/500–year	Extensive	Occasional/Unlikely	Critical	High	Medium
Flood: Localized/Stormwater	Significant	Highly Likely	Limited	Medium	Medium
Hazardous Materials Transportation (interstates, railroads, pipelines)	Limited	Likely	Limited	Medium	Low
Landslide, Debris & Mud Flows	Significant	Likely	Critical	Medium	Low
Levee Failure	Limited	Unlikely	Limited	Low	Low
Severe Weather: Extreme Cold, Snow, and Freeze	Significant	Highly Likely	Limited	Medium	Medium
Severe Weather: Extreme Heat	Significant	Likely	Critical	Medium	Medium
Severe Weather: Heavy Rains and Storms (wind/tornado/hail, lightning)	Significant	Highly Likely	Critical	Medium	High
Subsidence	Significant	Likely	Negligible	Medium	Medium
Volcano	Significant	Unlikely	Limited	Low	Low
Wildfire (smoke, tree mortality, conflagration)	Extensive	Highly Likely	Catastrophic	High	High

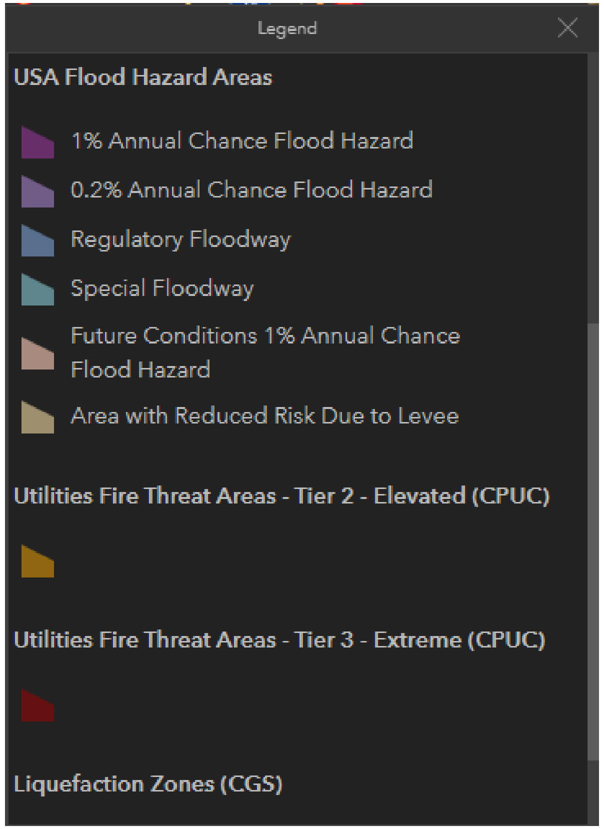
Hazards to Mitigate with Resiliency Measures

The FEMA map shows those areas with an approved Hazard Mitigation Plan (HMP). There are a few counties in California that do not currently have a plan in place.





Hazards to Mitigate with Resiliency Measures



Resiliency Valuation Methodology
I. Baseline Assessment

HYPOTHETICAL USE CASES ==>	Example 1: Fire Station	Example 2: Main Street	Example 3: Substation	Example 4: County
1. Geography	Fire Station property	Feeder serving Main Street	Area served by substation, circuits and feeders	County lines
2. Define Load Tiers	**Critical:** Fire Station; **Priority:** Nothing; **Discretionary:** Nothing	**Critical:** Police station, Public Works building; **Priority:** Bank, grocery store; **Discretionary:** retail stores	**Critical:** 2 Police stations, Hospital, Emergency Call Center; Community Resource Center, Water and Wastewater facility; **Priority:** 5 grocery stores, 3 gas stations, 4 banks, food distribution center; **Discretionary:** 140 residential customers, 10 businesses	**Critical:** 25 Police Stations, 15 Fire Stations, 6 Hospitals, 8 Water and wastewater facilities, 3 CRCs, evacuation center, 4 Food banks, 3 telecommunications centers; **Priority:** 25 grocery stores, 15 banks, 40 full-service schools **Discretionary:** 3000 residential customers, 500 businesses, 300 retail stores
3. Resiliency Targets	**Critical:** 90% load profile for 72 hrs	**Critical:** 80% load profile for 24 hrs; **Priority:** 50% load for 24 hrs; **Discretionary:** 0% load	**Critical:** 85% load profile for 48 hrs; **Priority:** 40% load for 24 hrs; **Discretionary:** 50% load to DAC residential customers	**Critical:** 100% load profile for 24 hrs; **Priority:** 60% load for 24 hrs; **Discretionary:** 50% load to DAC residential customers

Resiliency Valuation Methodology
I. Baseline Assessment

HYPOTHETICAL USE CASES ==>	Example 1: Fire Station	Example 2: Main Street	Example 3: Substation	Example 4: County
4. All-Hazard Assessment	#1. PSPS power outages	#1. PSPS power outages; #2. flooding	Flooding, earthquake liquefaction zone, sea level rise	Wildfire (HFTD – Tier 3), high winds, high heat events
5. Current Resiliency Assessment baseline of Load Tiers * Not reflected here are noted historical and projected frequencies of each hazard per case study, nor are costs reflected here	**TARGET: Critical:** 90% load profile for 72 hrs; **Priority:** none; **Discretionary:** 10% load **CURRENT Resiliency from: Hazard #1** PSPS Power outages: **Critical:** 30% load profile for 4 – 8 hrs depending on curtailment and use	**TARGET: Critical:** 80% load profile for 24 hrs; **Priority:** 50% load for 24 hrs; **Discretionary:** 0% load **CURRENT Resiliency from: Hazard #1** PSPS Power outages: **Critical:** 50% load profile for 24 hrs; **Priority:** 0% load; **Discretionary:** 0% load **Hazard #2** Flooding: **Critical:** 0% load profile for 24 hrs; **Priority:** 0% load; **Discretionary:** 0% load	**Critical:** 85% load profile for 48 hrs; **Priority:** 40% load for 24 hrs; **Discretionary:** 50% load to DAC residential customers **CURRENT Resiliency from: Hazard #1** Flooding: **Critical:** 50% load profile for 24 hrs; **Priority:** 0% load; **Discretionary:** 0% load **Hazard #2** Earthquake liquefaction zone: **Critical:** 0% load profile for unknown hrs; **Priority:** 0% load; **Discretionary:** 0% load **Hazard #3** Sea level rise: **Critical:** 0% load profile for unknown hrs; **Priority:** 0% load; **Discretionary:** 0% load	**Critical:** 100% load profile for 24 hrs; **Priority:** 60% load for 24 hrs; **Discretionary:** 50% load to DAC residential customers **CURRENT Resiliency from: Hazard #1** Wildfire (HFTD Tier 3): **Critical:** 0% load profile for 24 hrs; **Priority:** 0% load; **Discretionary:** 0% load **Hazard #2** High winds: **Critical:** 70% load profile for unlimited hrs; **Priority:** 75% load; **Discretionary:** 80% load **Hazard #3** High heat events: **Critical:** 50% load profile for unlimited hrs; **Priority:** 30% load; **Discretionary:** 30% load

Resiliency Valuation Methodology
II. Mitigation Measure Assessment

- Using Resiliency Targets as guidelines develop mitigation measure options
- Identify Mitigation Measure Characteristics
- Identify costs (CapEx and O&M)

1. Identify Mitigation Measure Options

2. Assess ability of mitigation measures to reach Resiliency Targets for Hazards (in ranking order)

- Identify ability of Mitigation Measure to reach Resiliency Targets

❖ Resilience duration required
❖ Maximum duration of outage to withstand
❖ # and % of Critical, Priority and Discretionary loads served
❖ # of Critical Facilities
❖ # of Emergency Services
❖ # of Critical Infrastructure
❖ # of Community Resource Centers
❖ # of Essential Services
❖ # of Cumulative Customers without power

- Identify Risk-Spend Efficiency levels of Mitigation Measure Options according to highest level of Resiliency Targets met for highest ranking Hazards
- Combine Resiliency Scorecard results with All-Hazard Mitigation Analysis in comparison of Mitigation Measure Options

3. Compare costs of Mitigation Measures Options that achieve highest level of Resilience

Resilience Mitigation Measure Characteristics

Mitigation Measure Characteristic	Metric
Start-up or islanding crossover transition time (intermittent downtime before specified backup is available)	Time – minutes, hrs
Notification time/Advanced notice needed for backup available at specified load/duration	Time – minutes, hrs
Duration of backup – with no other inputs	Time – minutes, hrs
Load Capacity (which loads are backed up and how much load (Critical, Priority, Discretionary)	kWh, MWh
Fuel Type/Fuel Availability	Unit of fuel, availability before/during islanding
Emissions level – GHG and particulates	MMCO2, PPM
Geographic boundary	Location on geographic map, sq ft, sq mi

Resiliency Valuation Methodology
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  - ❖ # and % of Critical, Priority and Discretionary loads served
  - ❖ # of Critical Facilities
  - ❖ # of Emergency Services
  - ❖ # of Critical Infrastructure
  - ❖ # of Community Resource Centers
  - ❖ # of Essential Services
  - ❖ # of Cumulative Customers without power

3. Compare costs of Mitigation Measures Options that achieve highest level of Resilience

- Identify Risk-Spend Efficiency levels of Mitigation Measure Options according to highest level of Resiliency Targets met for highest ranking Hazards
- Combine Resiliency Scorecard results with All-Hazard Mitigation Analysis in comparison of Mitigation Measure Options

All-Hazard Approach to Assess Resiliency Measures

Mitigation measures to achieve the minimum resilience level for the geographic area defined would be compared in terms of cost, effectiveness (based on the effect on the resiliency trapezoid and/or meeting resiliency targets) and the degree to which the measure would mitigate various hazards (risk-assessment based on weighted all-hazard probability and impact analysis). This type of mitigation measure comparison may reveal vulnerabilities and benefits previously unrealized.

As an example:

i. Measure A mitigates Hazard Z
ii. Measure B mitigates Hazard Z & Y
iii. Measure C mitigates Hazard X
iv. Measure D mitigates Z, Y & X
v. Measure D offers highest level of resilience -- at what cost?
vi. Compare with costs of either Meas. A + Meas B. + Meas. C OR Meas B + Meas. C
vii. Compare with Resilience Measure Characteristics (notification, crossover, duration, fuel type, load capacity, emissions, geographical impact)

Measure	Mitigates Hazard	Ranking	Cost *	Resiliency Trapezoid
A	Z	1	$40,000	Preparation
B	Z, Y	2	$100,000	Preparation/Magnitude
C	X	1	$400,000	Adaptation/Recovery
D	Z, Y, X	3	$520,000	Preparation (Z, Y), Magnitude (Y), Adaptation (X), Recovery (X)

*Cost figures are arbitrary and for illustration purposes only

Resiliency Valuation Methodology
II. Mitigation Measure Assessment

Hypothetical Example 1: Fire Station

Gap Analysis:

Target: 90% **Critical** load for 72 hrs duration of outage

Current: 30% **Critical** for 4-8 hrs depending on load shedding

Hazard 1: PSPS	Option 1	Option 2	Option 3
Proposed Mitigation	Diesel B.U. Generator	NG Fuel Cell	PV + Lith Batt + NG FC
Effect of Mitigation on Target	100% CL, indefinite duration based on fuel availability	100% CL, indefinite duration based on fuel availability	100% CL indefinite duration w/o fuel interruption; 80% CL w/some intermittent interruption if NG not avail.
Resilience Enhancement cost	$40k	$60k	$100k

Resiliency Valuation Methodology
II. Mitigation Measure Assessment

Hypothetical Example 2: Main Street

Gap Analysis:

Target**:** 80% **Critical** for 24 hrs; 50% **Priority** for 24 hrs; 0% **Discretionary**

Current: 30% **Critical** for 4-8 hrs depending on load shedding

Hazard 1: PSPS	**Option 1**	**Option 2**	**Option 3**
Proposed Mitigation	Diesel Generator MG	New feeder, switch and sectionalizer/ reclosers	IFOM Batt Bank + 3rd party Linear generator
Effect of Mitigation on Target	75% CL; 20% PL; 0% DL	0-100% CL, 0-100% PL; 0-100% DL dependent on wind conditions	100% CL; 60% PL; 20% DL
Hazard 2: Flooding	**Option 1**	**Option 2**	**Option 3**
Effect of Mitigation on Target	20% CL; 0% PL; 0% DL	50% CL, 50% PL, 50% DL	60% CL; 60% PL; 10% DL
Resilience Enhancement cost	$80k	$200k	$100k

Resiliency Valuation Methodology
II. Mitigation Measure Assessment

Hypothetical Example 3: Substation

Gap Analysis:

Target**:** 85% **Critical** for 48 hrs; 40% **Priority** for 24 hrs; 50% **Discretionary** to DAC residential customers

CURRENT**: Hazard #1** Flooding: 50% **Critical** for 24 hrs; 0% **Priority**; 0% **Discretionary**

Hazard #2 Earthquake liquefaction zone: 0% **Critical** for unknown hrs; 0% **Priority**; 0% **Discretionary**

Hazard #3 Sea level rise: 0% **Critical** for unknown hrs; 0% **Priority;** 0% **Discretionary**

Hazard 1: Flooding	**Option 1**	**Option 2**	**Option 3**
Mitigation Measure	RNG Fuel Cell + PV + Lith Batt MG	Distribution upgrade, limited undergrounding	Public Private Partnership IFOM MG, PV, Flywheel, H2 FC, Batt
Effect of Mitigation on Target	75% CL; 20% PL; 0% DL	60% CL; 35 % PL; 30% DL	100% CL; 60% PL; 20% DL
Hazard 2: Earthquake Liquefaction zone	**Option 1**	**Option 2**	**Option 3**
Effect of Mitigation on Target	20% CL; 0% PL; 0% DL	40% CL, 10% PL, 0% DL	60% CL; 60% PL; 10% DL
Hazard 3: Sea Level Rise	**Option 1**	**Option 2**	**Option 3**
Effect of Mitigation on Target	20% CL; 0% PL; 0% DL	60% CL, 50% PL, 30% DL	90% CL; 40% PL; 10% DL
Resilience Enhancement cost	$800K	$4.1M	$1.8 M

Resiliency Valuation Methodology
II. Mitigation Measure Assessment

Hypothetical Example 4: County

Gap Analysis:

Target: 100% **Critical** for 24 hrs; 60% **Priority** for 24 hrs; 50% **Discretionary** to DAC residential customers

CURRENT: **Hazard #1** Wildfire: 0% **Critical** for 24 hrs; 0% **Priority**; 0% **Discretionary**

Hazard #2 High Winds: 70% **Critical** for unlimited hrs; 75% **Priority**; 80% **Discretionary**

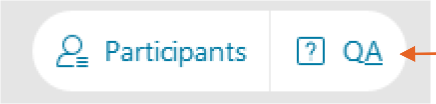
Hazard #3 High heat events: 50% **Critical** for unlimited hrs; 30% **Priority;** 30% **Discretionary**

Hazard 1: Wildfire	**Option 1**	**Option 2**	**Option 3**
Mitigation Measure	Covered Conductors, undergrounding, new feeders and reclosers, sectionalizers	3 strategically located IFOM MGs with dispatchable BTM DERs	Public Private Partnership IFOM MG, PV, Batt
Effect of Mitigation on Target	75% CL; 20% PL; 0% DL	60% CL; 35 % PL; 30% DL	50% CL; 20% PL; 0% DL
Hazard 2: High Winds	**Option 1**	**Option 2**	**Option 3**
Effect of Mitigation on Target	60% CL; 20% PL; 40% DL	100% CL, 40% PL, 10% DL	50% CL; 20% PL; 20% DL
Hazard 3: High Heat Events	**Option 1**	**Option 2**	**Option 3**
Effect of Mitigation on Target	50% CL; 20% PL; 20% DL	100% CL, 50% PL, 30% DL	50% CL; 20% PL; 20% DL
Resilience Enhancement cost	$5.65M	$4.1M	$ 2.5M

Discussion and Q&A

WebEx Tip

Option 1:



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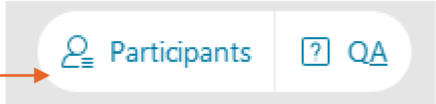

2. Raise your hand by clicking the hand icon.

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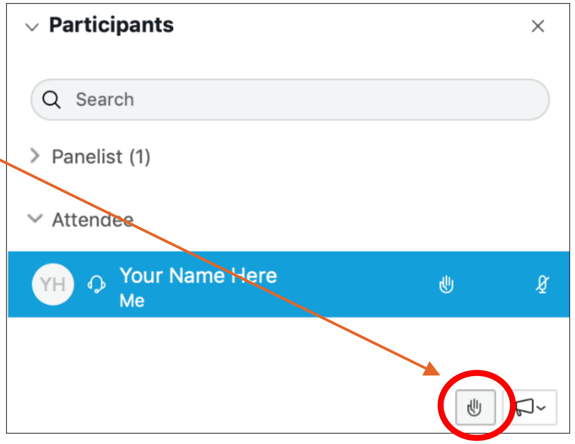

Discussion Questions

- How do you balance wires and non-wires alternatives to gain a fair comparison?
- How do we weigh the benefits and disadvantages of each resiliency measure?
- What level of resiliency measure expenditure is reasonable? In other words, what is a reasonable risk-spend efficiency ratio?

What are your questions?

Exceptional service in the national interest

Sandia National Laboratories




Electric Grid Resilience and Reliability Co-optimization

Dr. Brian J. Pierre

Sandia National Laboratories

May 2021

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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  - And others

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  - University of Texas

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  - U.S. Department of Energy Office of Electricity Advanced Grid Modeling program led by Dr. Ali Ghassemian
  - Sandia National Laboratories LDRD program

Topics to Cover

- Grid Reliability and Grid Resilience Intro
- Grid Reliability Optimization
- Grid Resilience Optimization
  - Investments (planning)
  - Preemptive Action
  - Restoration Process
- Inclusion of Grid Dynamics and Cascading Failures
- Co-optimization of Reliability and Resilience
- Identifying Critical and Vulnerable Nodes in the Grid

Overall Goals

Develop optimization models which find the optimal investments, preemptive action, and restoration decisions to improve reliability, resilience, and a weighted combination of the two.

- Help utilities see the trade-offs between investing more heavily in reliability or resilience.

- Help utilities develop rate recovery cases to justify large scale investments, by quantifying how that investment will improve their reliability and/or resilience.

- Inform utilities and their stakeholders, DOE, DHS, and policy makers of cost-effective infrastructure investment decisions that improve reliability and/or resilience.

Grid Reliability vs. Grid Resilience

- Grid reliability is the ability of the electric grid to supply customers with electricity.
- Typical metrics used to measure grid reliability are:
  - SAIDI – System Average Interruption Duration Index. Based on the duration an average customer is without power, e.g. 100 min. per year.
  - SAIFI – System Average Interruption Frequency Index. Based on the frequency an average customer is without power, e.g. 1.2 per year.
- Grid reliability focuses on high frequency, low consequence events. Local outages that occur every day.
  - Animals – e.g. squirrels, birds
  - Lightning
  - Wind/trees
  - Car accidents

- Grid resilience:

"the ability to **<u>prepare</u>** for and **<u>adapt</u>** to changing conditions and **<u>withstand</u>** and **<u>recover</u>** rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents." - Presidential Policy Directive (PPD) 21.

- Resilience - High consequence less frequent events
  - Hurricanes
  - Earthquakes
  - Severe winter storms
  - EMPs and GMDs
  - Large fires
  - Physical attack

Current Practice – Improving Reliability and Resilience

Sandia National Laboratories

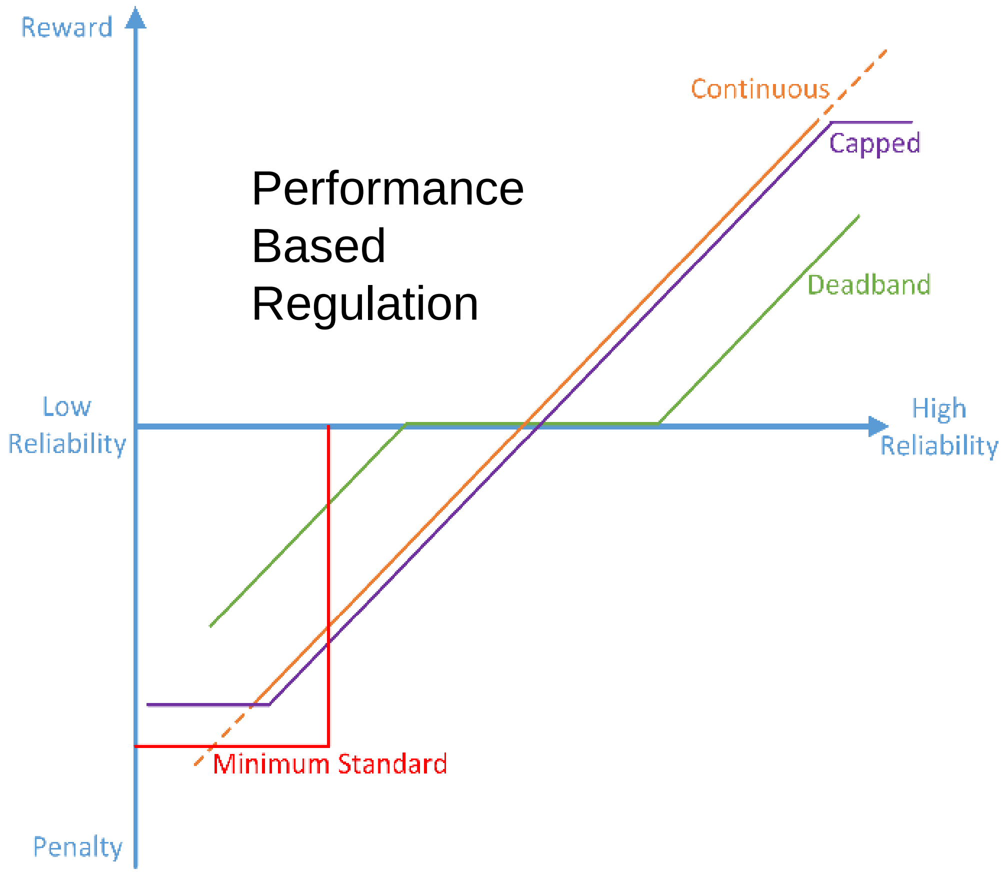
	RELIABILITY	RESILIENCE
CURRENT PRACTICE	• A reactive method instead of proactive • List of the past year of outages • Go down the list fixing the worst-case events	• No accepted methodology for resilience yet • Mostly in the research stage or specific application stage • Methods focus on specific technologies (e.g., microgrids, energy storage)

OUR R&D	• A proactive method instead of reactive
	• A probabilistic approach
	• An optimization methodology to identify the optimal small-scale investments
		• A three-stage methodology to cover all timelines
		  • Investment planning
		  • Preemptive action
		  • Restoration
		• An optimization methodology to capture the optimal decisions in each stage

Co-optimize to view tradeoffs

Utilities are Incentivized to be Reliable not Resilient

- Utilities are often incentivized to be more reliable (improve their SAIDI and SAIFI metrics)
- Some utilities have performance based regulation (PBR)
- Large scale events (severe winter storms, hurricanes, etc.) are removed from the SAIDI and SAIFI metrics
- Less incentive to invest in resiliency

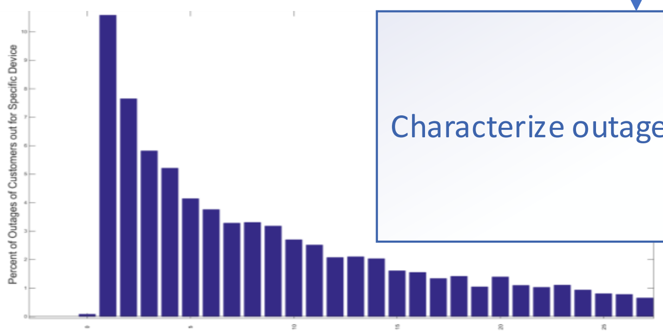


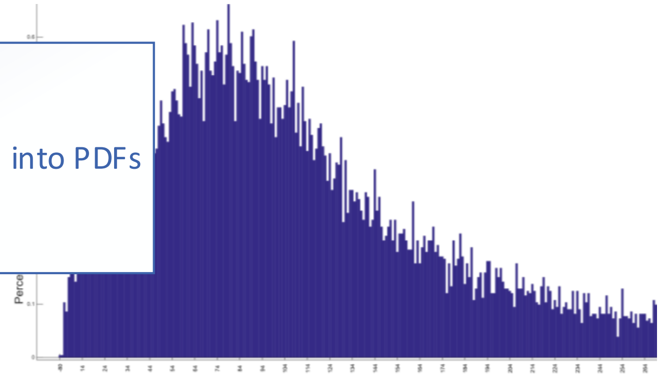
Note that PBR can be focus on many grid aspects: reliability, efficiency, customer service, green house gas reduction, and more.

Overall Reliability Investment Optimization Framework

Historical Outage Data (e.g. list of outages from 2014-2019)
Duration, Number of customers, Cause, Device type, Feeder ID, Device ID

Characterize outage data into PDFs





Monte Carlo Sample PDFs
(modified with engineering judgment, e.g. increasing failure probability of older devices)

Scenario 1
2020 hypothetical outage list 1

Scenario 2
2020 hypothetical outage list 2

...

Scenario *n*
2020 hypothetical outage list *n*

Investment Data:
Option, Impact, Cost.
Example: Add squirrel preventive measures. Reduces probability of outage to squirrels in this area. Cost: $X.

Optimization model
(Dynamic programming algorithm or Mixed integer programming method)

Budget

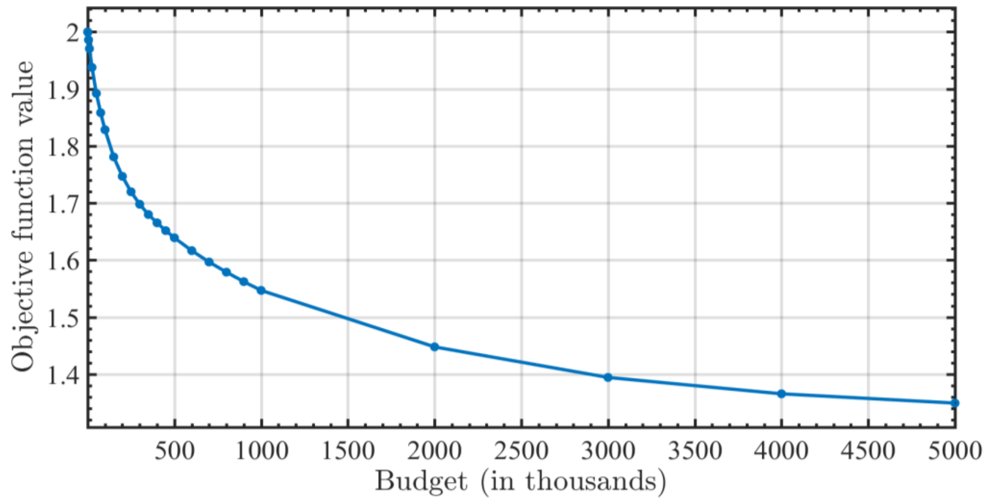
System Total Customers

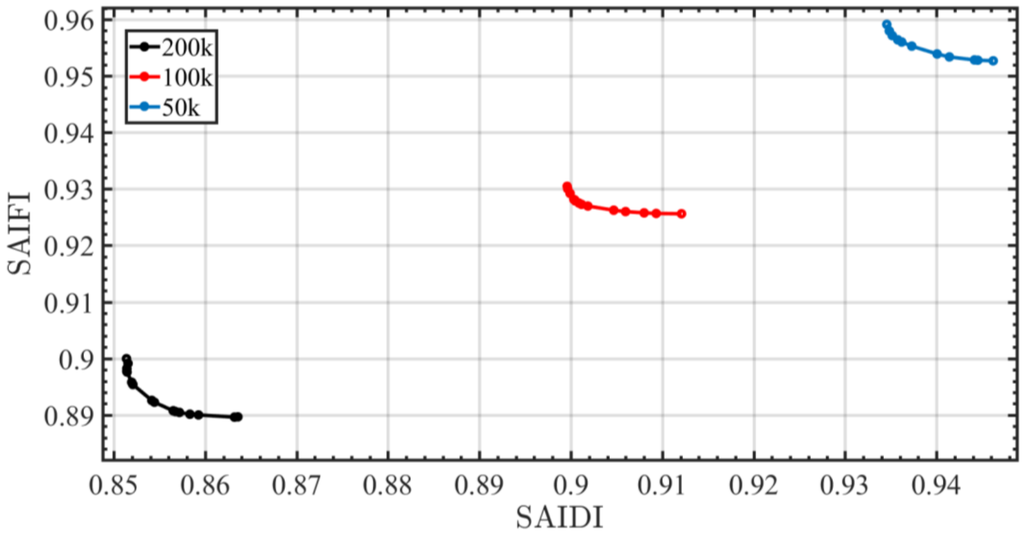
Optimal investments
(The investments that will improve the SAIDI and SAIFI of the *n* Scenarios the most within budget)

Expected new 2020 SAIDI and SAIFI

Reliability Investment Optimization Model

$$minimize\left(\frac{SAIDI_{upgraded}}{SAIDI_{baseline}}+\frac{SAIFI_{upgraded}}{SAIFI_{baseline}}\right)$$





Model details

- **Goal:** Determine the optimal small-scale investments to improve power distribution system reliability
- **Inputs to model:** Historical outage data, investment impact data, investment cost data
- **Model type:** Nonlinear mixed integer program Linearized through new and old techniques [1] or a Dynamic Programming Model [2].
- **Model efficiency (scalability):** Great efficiency, especially for larger systems.

1. Brian J. Pierre, Bryan Arguello, "Investment Optimization to Improve Power Distribution System Reliability Metrics," Proceedings IEEE Power & Energy Society General Meeting, Aug. 2018.
2. S. Raja, B. Arguello, B. J. Pierre, "Dynamic Programming Method to Optimally Select Power Distribution System Reliability Upgrades," *IEEE Open Access Journal of Power and Energy*, vol. 8, pp. 118-127, Feb. 2021.

Three Stages to Grid Resilience Optimization

1. Long-term Planning – Optimal investments (hardening decisions) considering years in advance, and a regional threat scenarios to become resilient to.
2. Preemptive Action – Given a warning of a storm or possible catastrophic event may take place, how to redispatch, reconfigure, and preposition resources to help brace for the event.
3. Restoration – The event has stuck the grid, what is the optimal multi-time period restoration process to optimally return critical loads to service.

Three Stage Resilience Optimization Problem

1st Stage (Investment)

Decides investments x.
Minimizes Conditional Value at Risk (CVaR)

$$\min_{x \in \mathcal{X}} CVaR_f^{\epsilon}\left[\tilde{\ell}(x,f)\right]$$

2nd Stage (Preemptive Action)

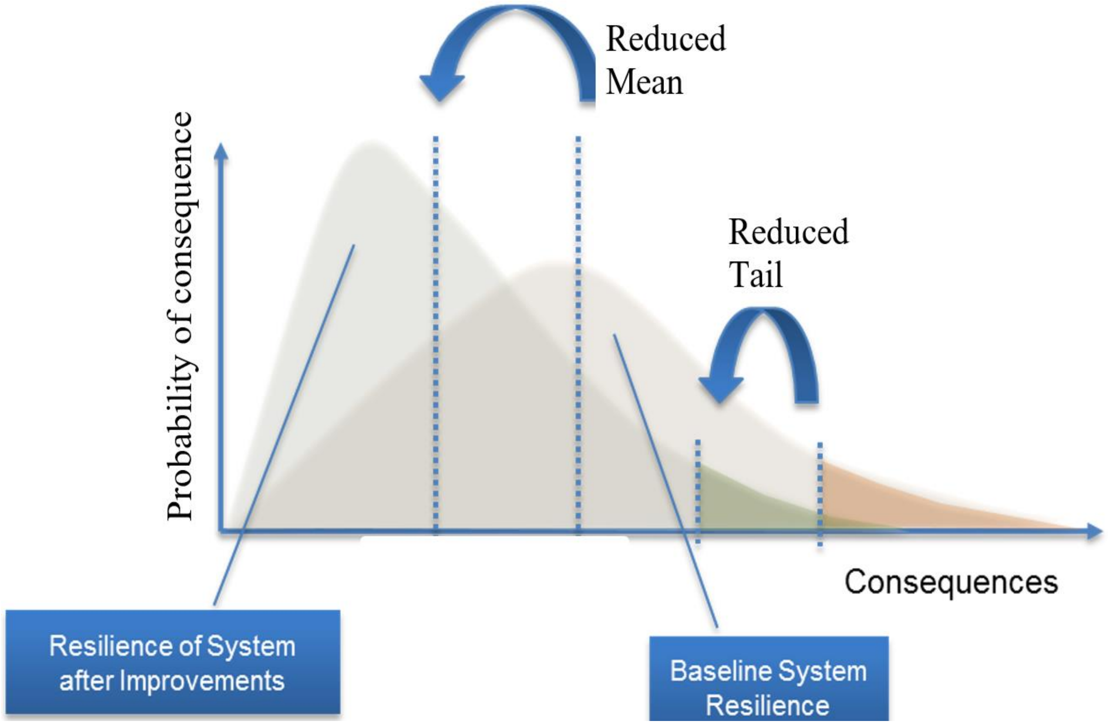
Decides pre-emptive action z.
Minimizes expected value.

$$\tilde{\ell}(x,f) = \min_{z \in \mathcal{Z}(x)} \mathbb{E}_{e|f}\left[\hat{\ell}(z,x,e)\right]$$

3rd Stage (Restoration)

Decides restoration variables y.
Minimizes deterministic value.

$$\hat{\ell}(z,x,e) = \min_{y \in \mathcal{Y}(x,z,e)} \ell(y,e)$$



Two-stage Preemptive Action Optimization

<u>2nd Stage</u>
<u>(Pre-Emptive Action)</u>
Decides pre-emptive action z.
Minimizes expected value.

$$\min_{z \in \mathcal{Z}} \mathbb{E}_e\left[\hat{\ell}(z,e)\right]$$

<u>3rd Stage</u>
<u>(Restoration)</u>
Decides restoration variables y.
Minimizes deterministic value.

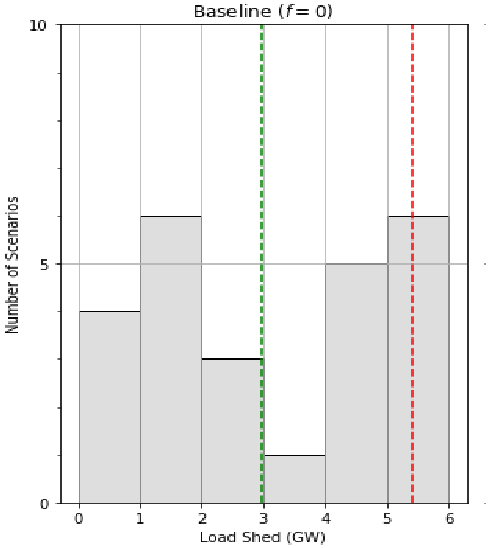
$$\hat{\ell}(z,e) = \min_{y \in \mathcal{Y}(z,e)} \ell(y,e)$$

- Given a warning an event may occur, how to optimally prepare your system for that event, and optimally recover from the event.
- Example 1: given a 24-hour warning a hurricane will strike a specific city, how to optimally dispatch limited flood walls around substations, to minimize load shed.
- Example 2: given a 24-hour warning a winter storm will occur, how to redispatch your generators to minimize load shed.

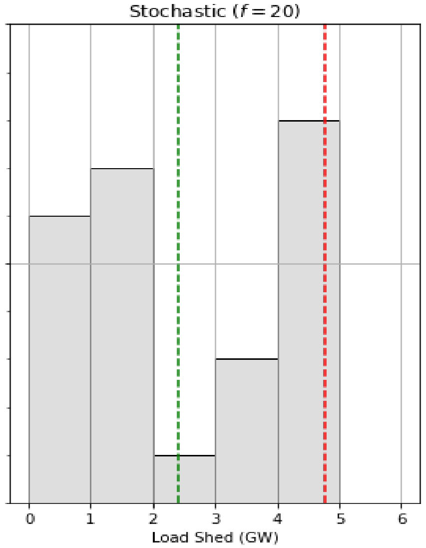
Grid Resilience with Preemptive Action

Baseline vs. Preemptive action

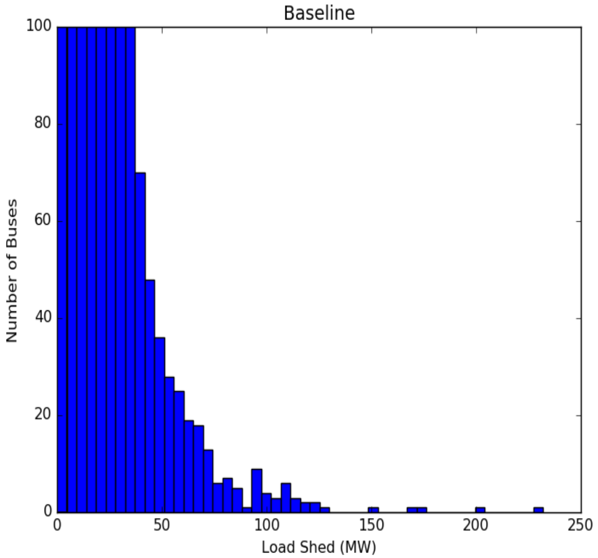
Optimizing for 25 hurricane scenarios



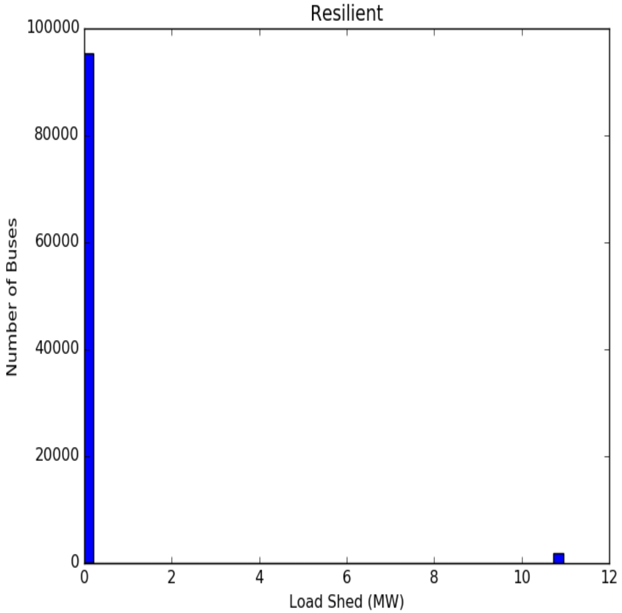
Simply prepositioning flood barriers in advance of a hurricane can significantly reduce consequence



Optimizing for 100 winter storm scenarios

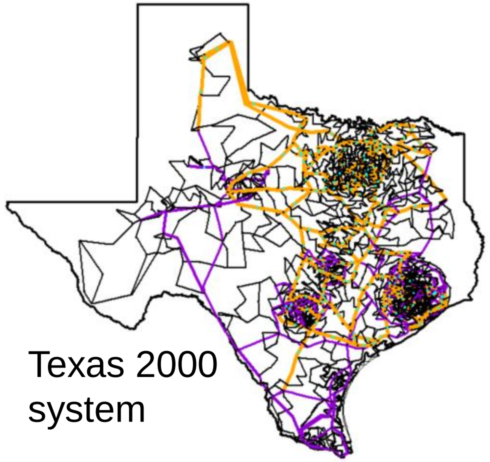


Simply redispatching generation in advance of a winter storm can significantly reduce consequence

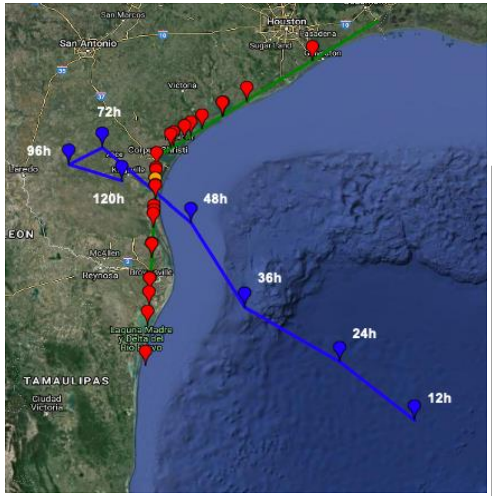


In partnership with University of Texas, Brent Austgen

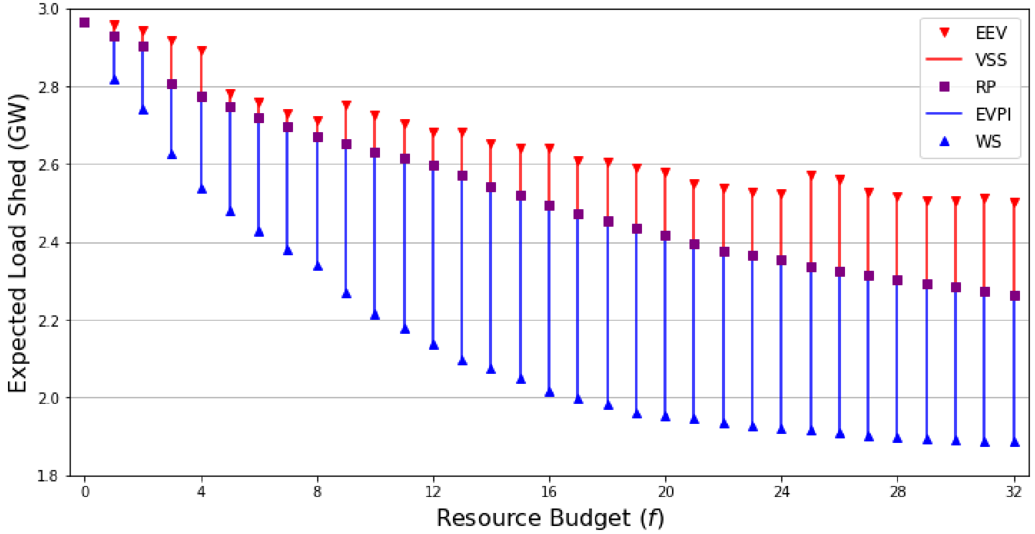
Results: Two-stage Preemptive Action Optimization



Texas 2000 system

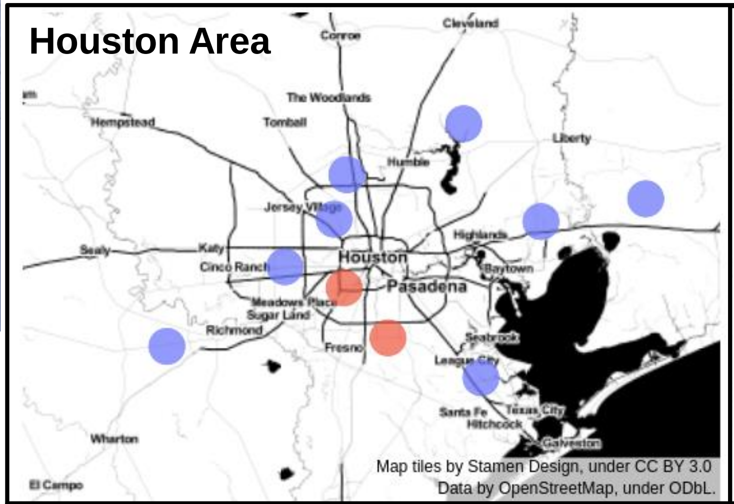


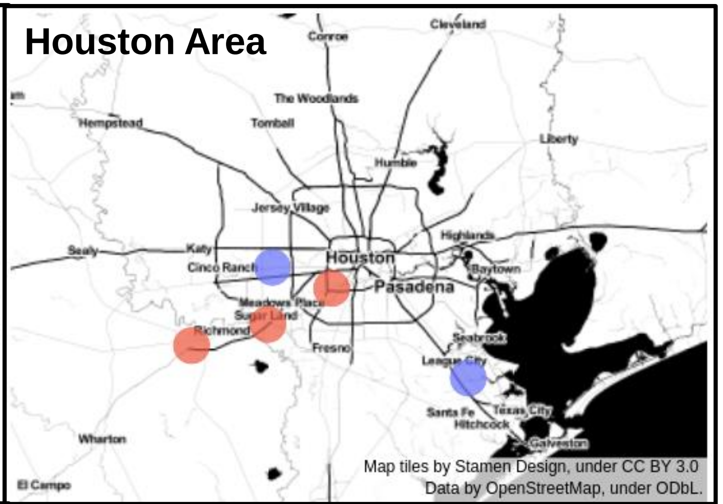
- Preemptive flood wall placement in Texas
- Increase resilience to 25 hurricane Harvey scenarios

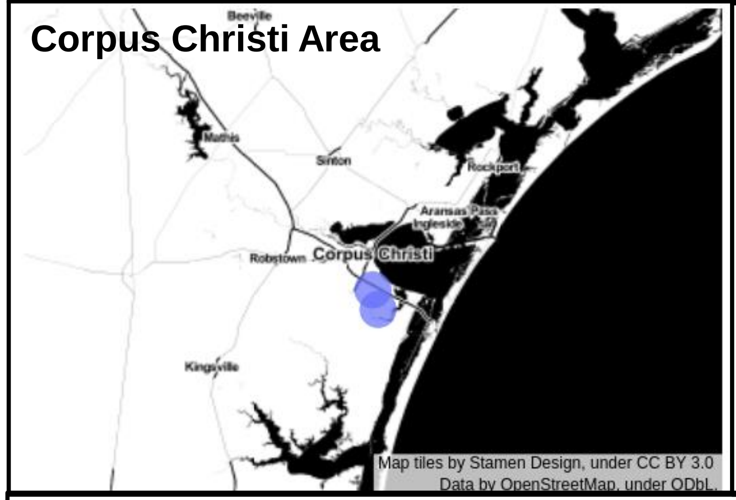


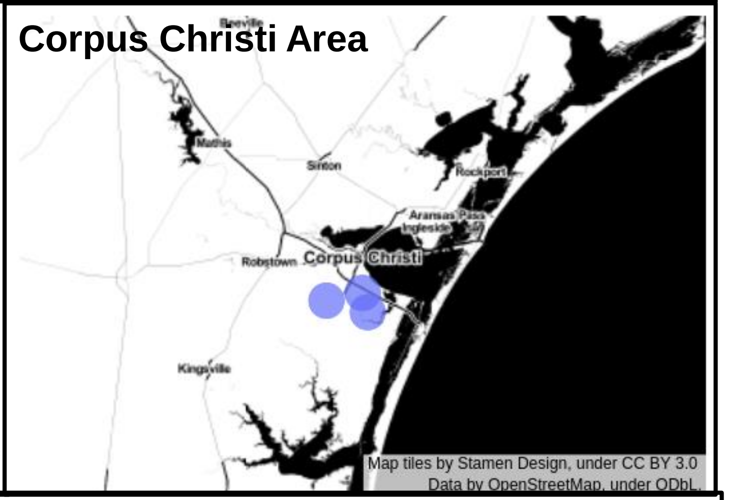
In partnership with University of Texas, Brent Austgen

Expected Value Solution	Stochastic Solution









blue circle = level 1 resilience **red circle = level 2 resilience**

Two-stage Investment/Restoration Optimization

1st Stage (Investment)

Decides investments x.
Minimizes Conditional Value at Risk (CVaR)

$$\min_{x \in \mathcal{X}} CVaR_f^{\epsilon}\left[\tilde{\ell}(x, f)\right]$$

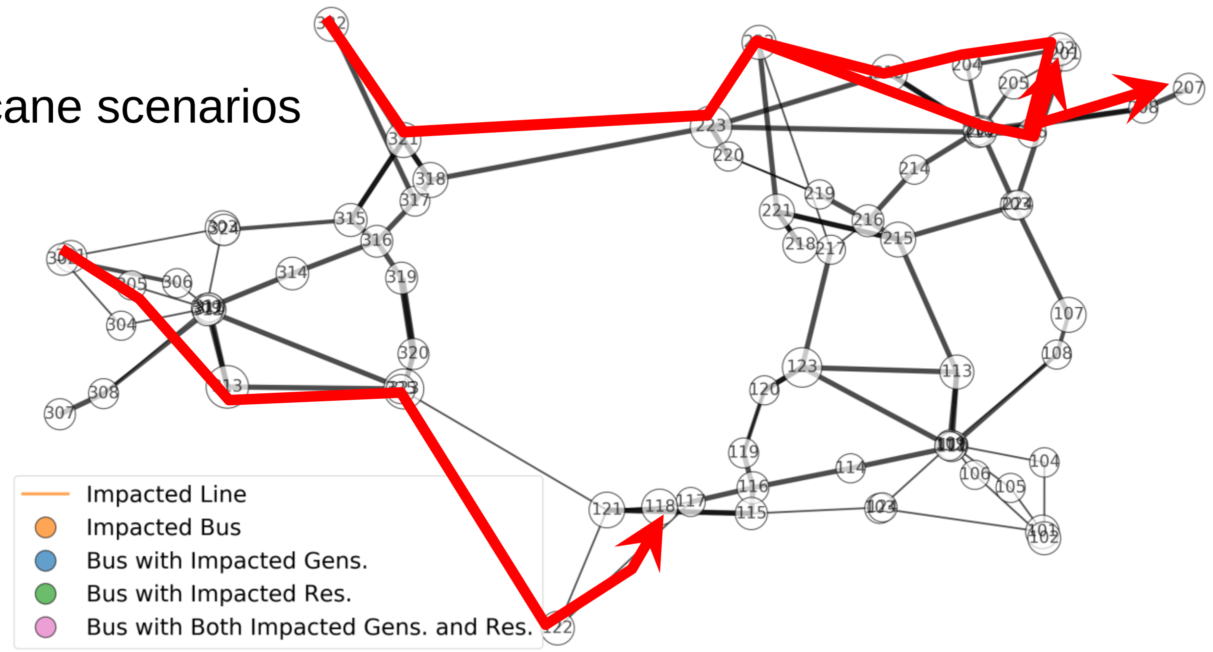
3rd Stage (Restoration)

Decides restoration variables y.
Minimizes deterministic value.

$$\hat{\ell}(z, x, e) = \min_{y \in \mathcal{Y}(x,z,e)} \ell(y, e)$$

RTS GMLC One-line Diagram

Hurricane scenarios video



Results: Two-stage Investment Optimization
Risk Neutral vs Risk Averse

No Investment

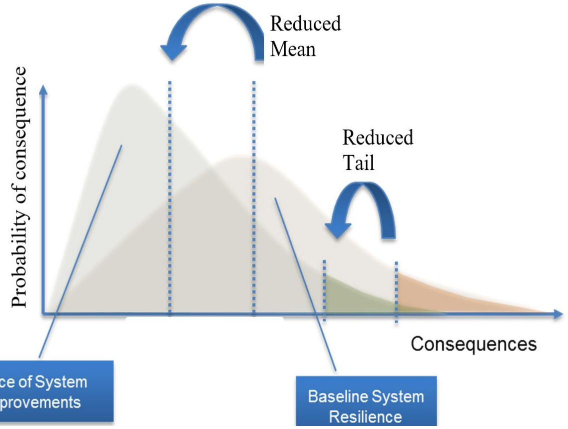
- No investment – base case impact from 45 hurricane scenarios.

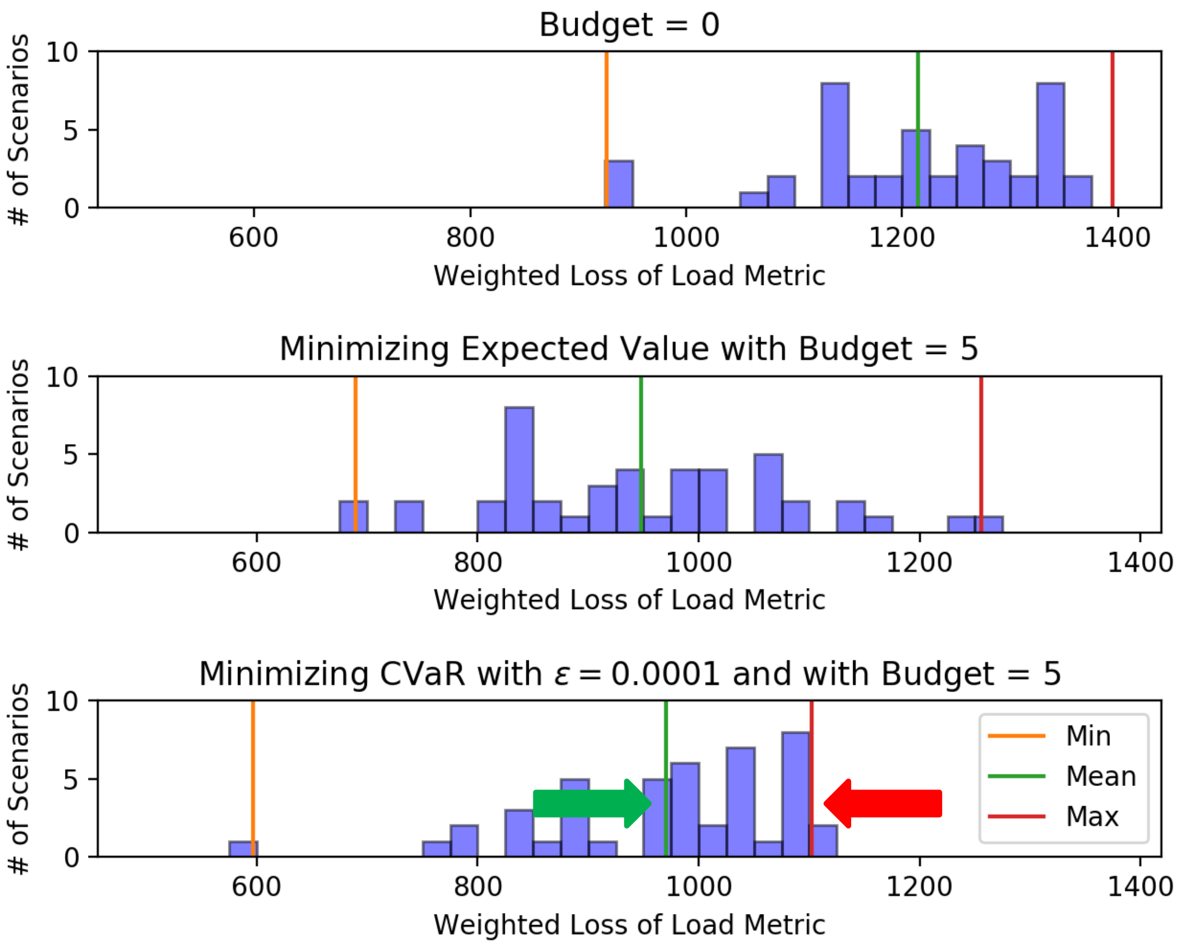
Risk Neutral

- Minimizes expected value of loss metric
  - Typical in previous investment optimization work

Risk Averse

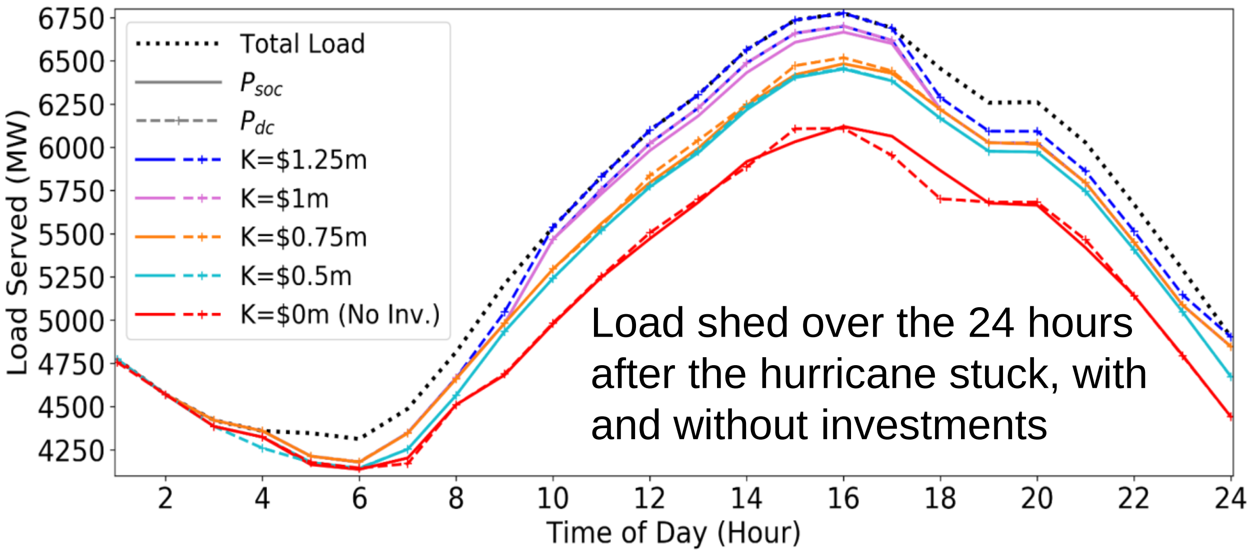
- Minimizes conditional value at risk metric

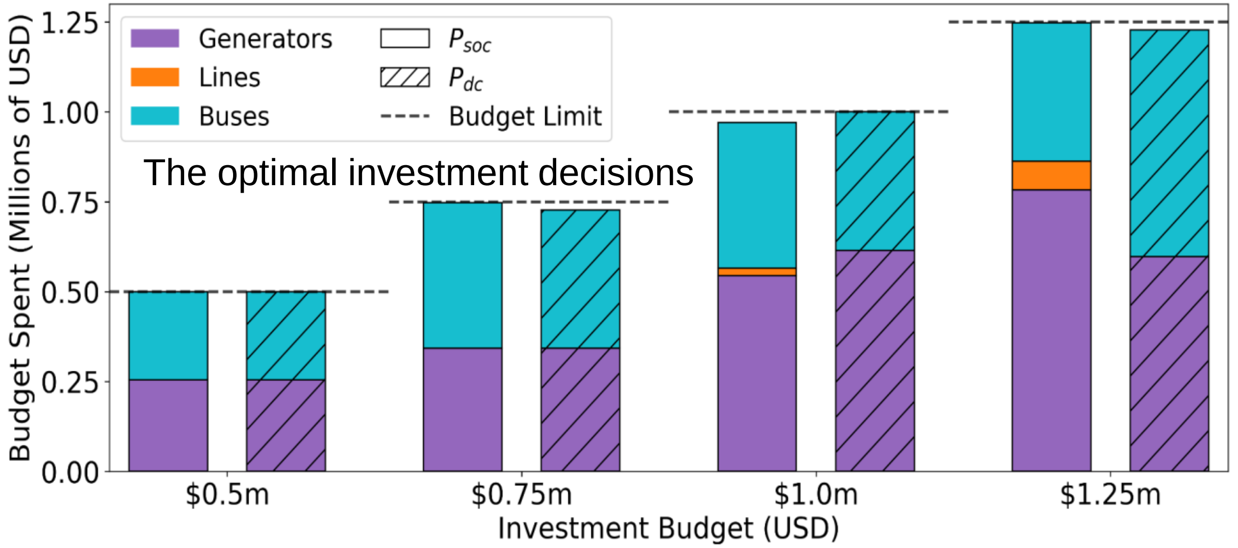




Minimizing CVaR as compared to expected value increases expected value and decreases maximum value

Results: Two-stage Investment/Restoration Optimization





$$minimize \sum_{s\in S}\sum_{t\in T}\sum_{b\in B} w_b p_{s,t,b}$$

Model details

- **Goal:** Determine the optimal large-scale hardening decisions and optimal restoration dispatch and transmission switching [2] to minimize weighted load shed to catastrophic events.
- **Inputs to model:** Event scenario data (e.g. hurricane scenarios), investment cost data
- **Model type:** A multi-time period two-stage stochastic mixed-integer linear optimization model, with SOCP power flow or DC power flow options [1].
- **Model efficiency (scalability):** difficult efficiency, especially for larger systems or more scenarios.

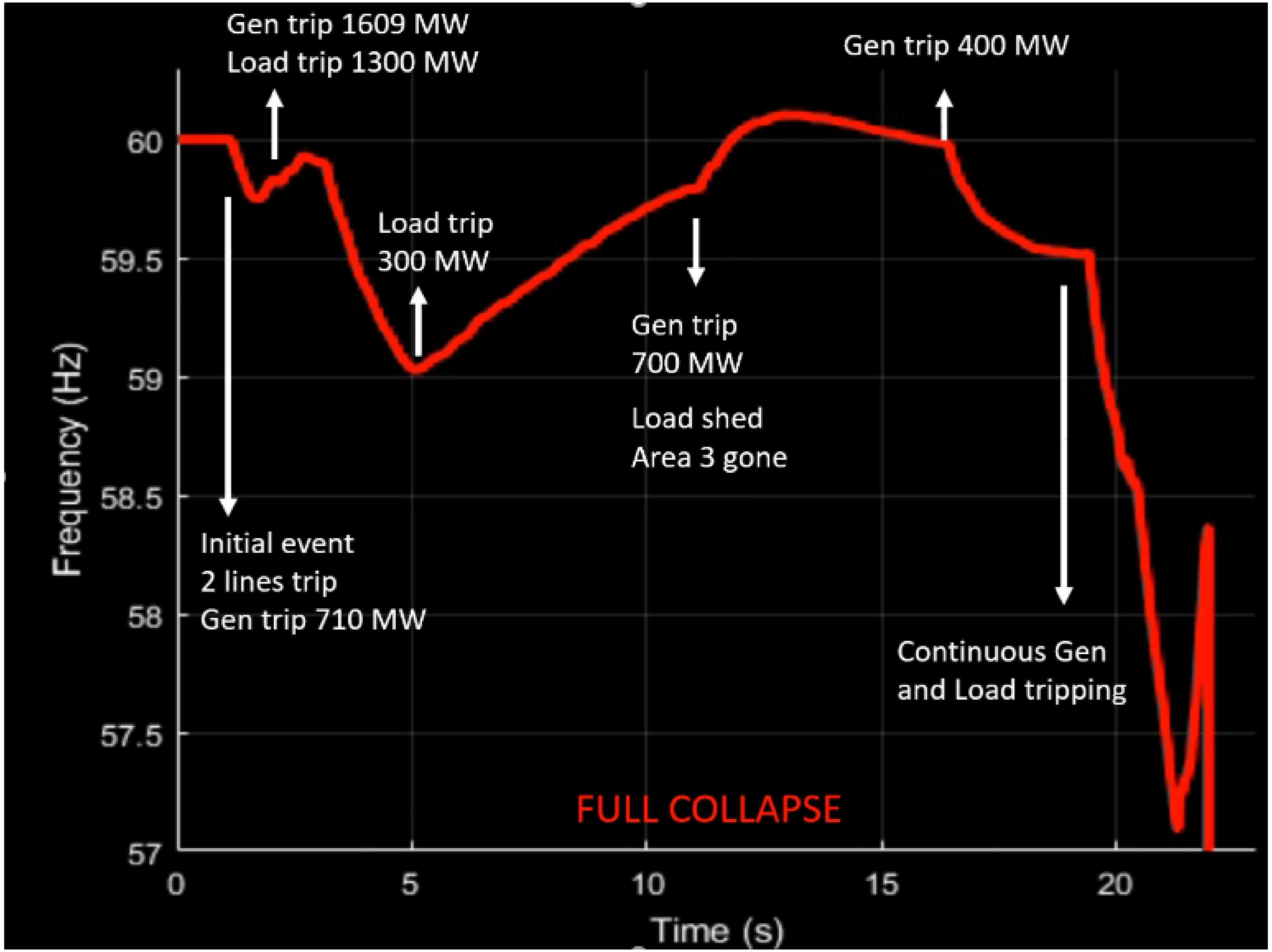
1. K. Garifi, E. Johnson, B. Arguello, B. Pierre, "Transmission Grid Resiliency Investment Optimization Model with SOCP Recovery Planning," under 2nd round of revise/resubmit *IEEE transactions on Power Systems*, 2021.
2. E. Johnson, S. Ahmed, S. Dey, JP Watson, "A K-Nearest Neighbor Heuristic for Real-Time DC Optimal Transmission Switching," submitted to *IEEE transactions on Power Systems*, 2021.

How to address cascading failures?

- The worst-case blackouts are often due to cascading failures
- Including the transient simulations within the optimization formulation allows the optimal decisions to protect against cascading failures

Grid Cascades Example

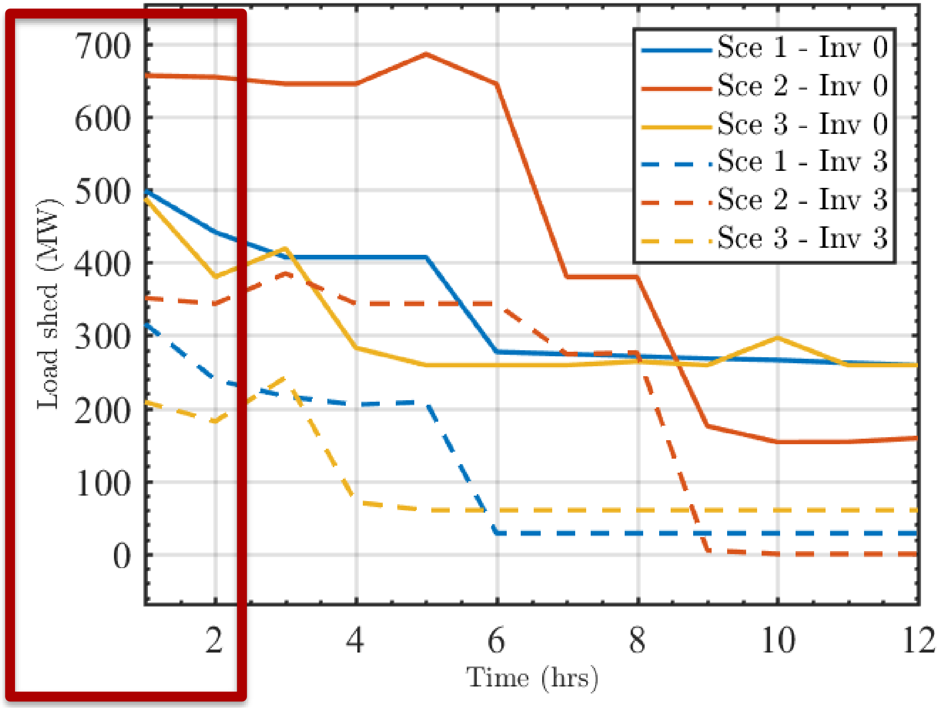
- An Earthquake event
- Trip:
  - 2 high voltage lines
  - 3 large generators
- IEEE RTS-96 System



Modeling the Initial Impact:
Transient Simulation vs. Steady-state Power Flow

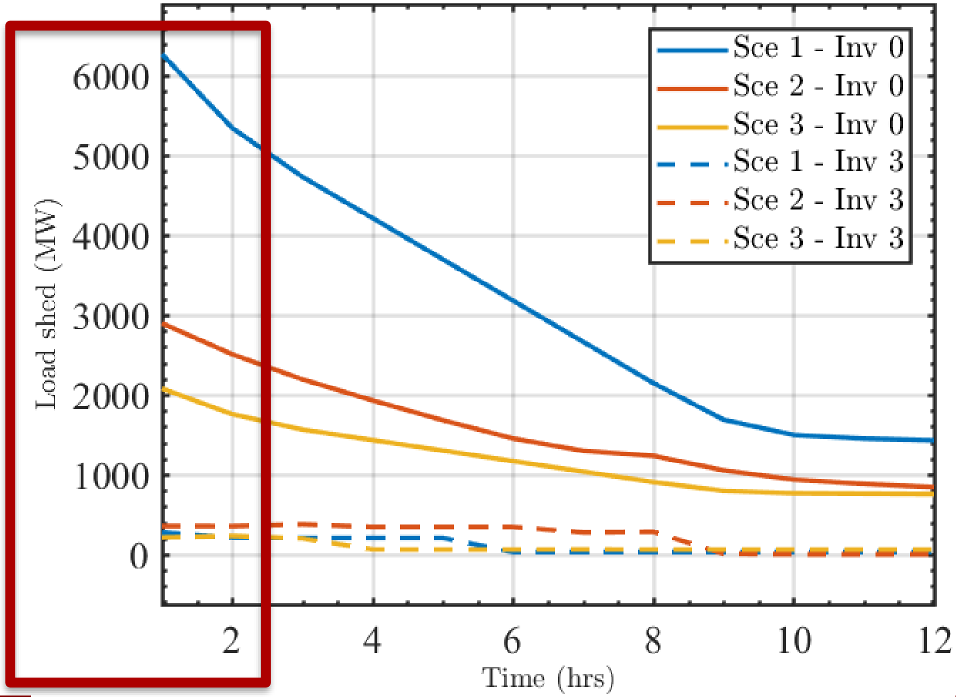
- Modeling the initial impact with DC power flow significantly underestimates the initial load shed because cascading failures are not accounted for.
- Example: three earthquake scenarios on the IEEE RTS-96 system
- Initial impact results are the initial operating points for the optimization formulation

Initial impact measured with DC power flow



Load shed over time for the three scenarios with no investments vs. 3 components hardened

Initial impact measured with transient simulation

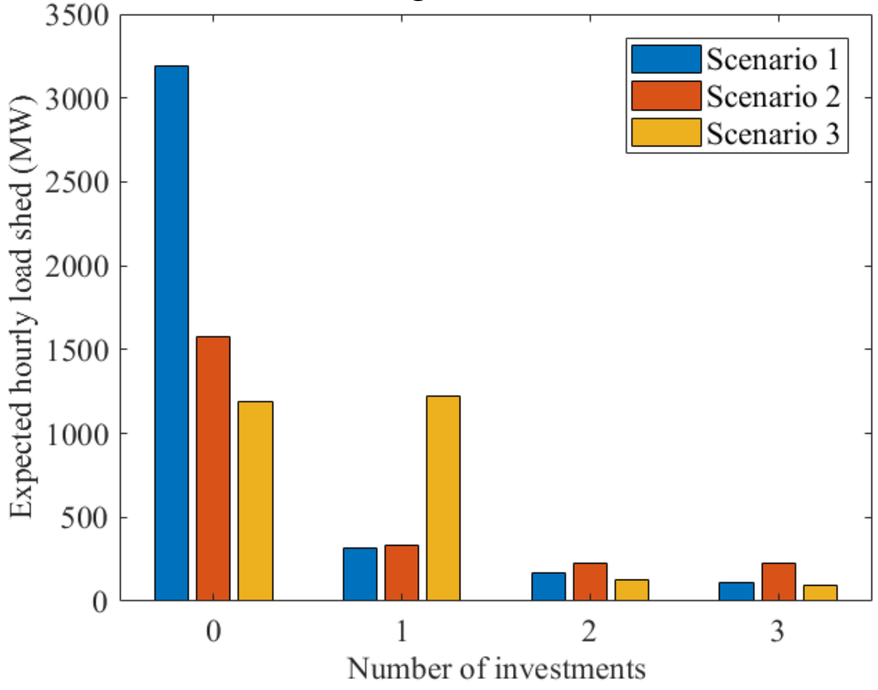


Results: Two-stage Investment/Restoration Optimization While Addressing Cascading Failures

$$\text{minimize} \sum_{s \in S} \sum_{t \in T} \sum_{b \in B} w_b p_{s,t,b}$$

<u>Expected hourly load shed over all time periods</u>

Diminishing returns on investment



Model details

Goal: Determine the optimal hardening locations to improve power system resilience while considering cascading outages and initial transients.

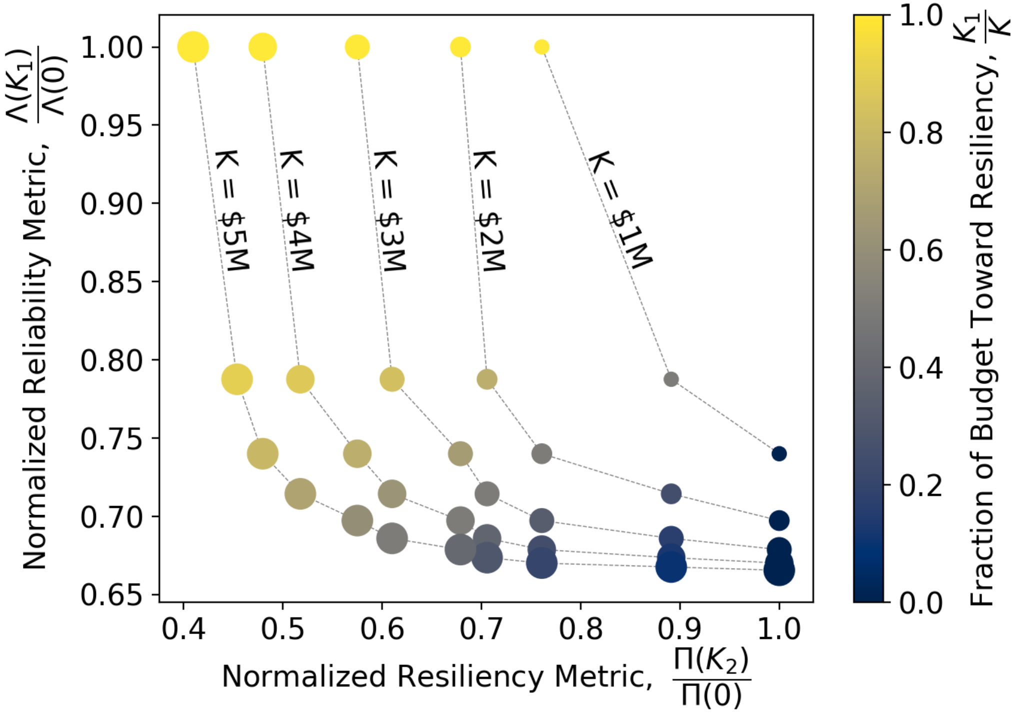
Inputs to model: Scenario data from threats listing component outages off time and recovered time. Investment cost data.

Model type: A multi-time period two-stage stochastic mixed-integer linear optimization model

Model efficiency (scalability): Poor due to transient simulations, can only handle ~9 investment package options. Good for narrowing down final options.

1. Brian J. Pierre, Bryan Arguello, Manuel Garcia, “Optimal Investments to Improve Resilience Considering Initial Transient Response and Long-term Impacts,” Proceedings IEEE Probabilistic Methods Applied to Power Systems (PMAPS), 2020.

Co-optimizing Reliability and Resilience – Combining Two-Stage Reliability and Resilience Models



- Find the tradeoffs between investing more heavily in reliability vs. resilience
- Help utilities develop rate recovery cases to justify large scale investments, by quantifying how that investment will improve their reliability and resilience.

Model details

Goal: Determine the optimal investments to improve power system reliability and resilience. See the trade offs between the two.

Inputs to model: Scenario data based on historical large-scale events that include outaged components and time tripped and time recovered. In addition, utility historical outage data, investment impact data, and investment cost data.

Model type: Nonlinear mixed integer program, linearized through new and old techniques

Model efficiency (scalability): Poor efficiency, especially for larger systems, and a large number of scenarios

Optimization Models Summary

Co-optimize Resilience and Reliability Decisions Options

☑ Resilience

Minimize Load Shed: ☑ weighted ☐ unweighted

Multi-time period:

Number of time periods: 24

Length of time period: 1 hour

Power Flow: ☑ SOCP ☐ DC

Optimal Transmission Switching: ☑

Initial Transients and Cascades: ☑

Stochastic Multiple Scenarios: ☑

☐ Reliability

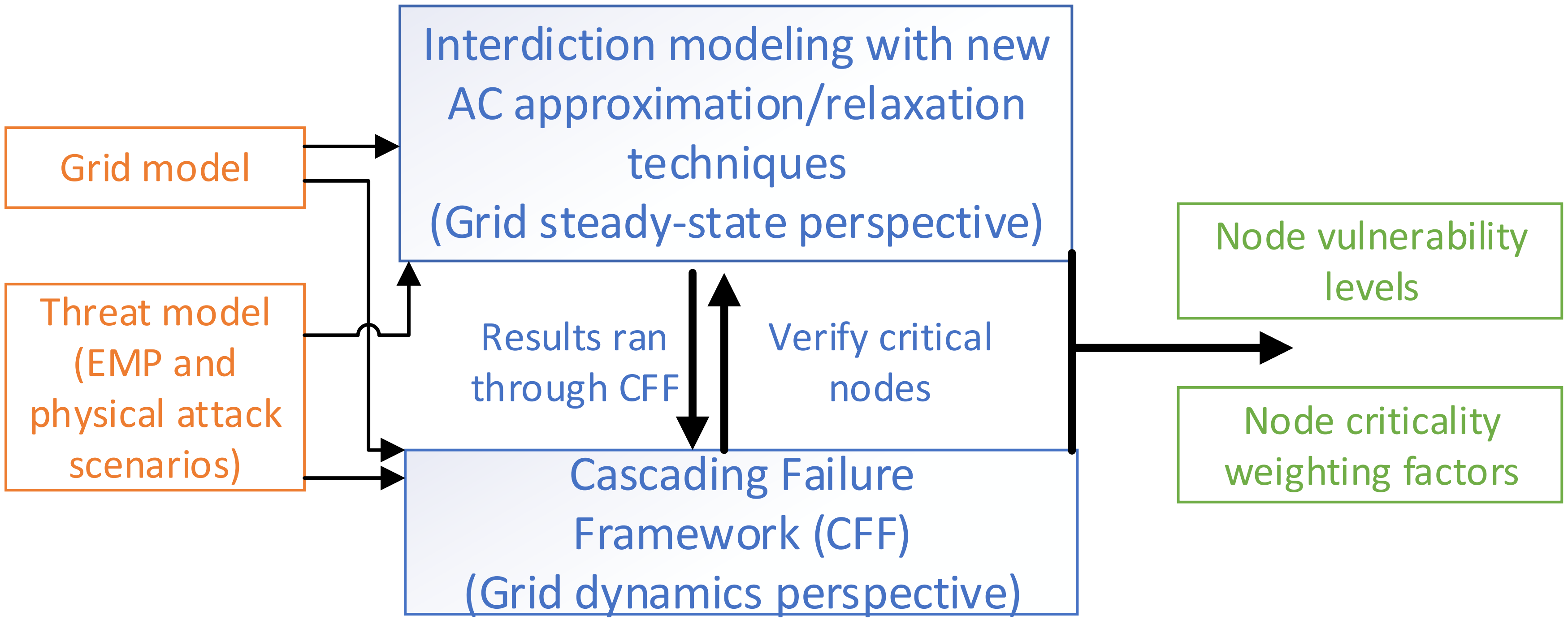
Minimize: ☑ SAIDI ☑ SAIFI

Model type: ☑ Dynamic Program ☐ MIP

Historical Data: ☐ Raw ☑ Probabilistic data

Identify Critical and Vulnerable Nodes

- A node will be deemed **critical** if its removal from service causes a severe consequence
  - Nodes with critical loads (e.g. military installations, water services, hospitals).
  - Nodes that repeatably cause cascading failures
- Node **vulnerability** level is high if a high percentage of threat scenarios cause the node to be removed:
  - Directly by the threat
  - Or indirectly from cascading outages.

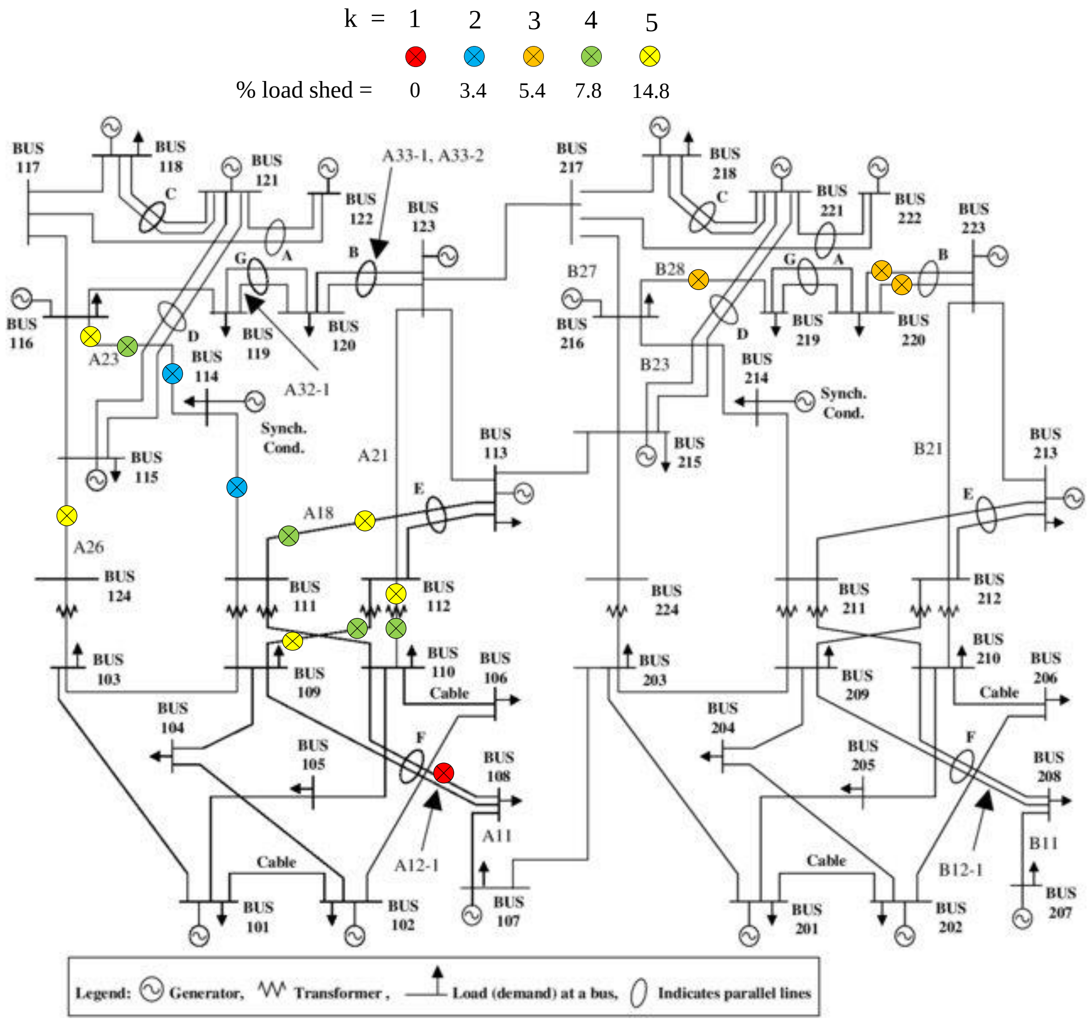


Valuable information for system owners and operators

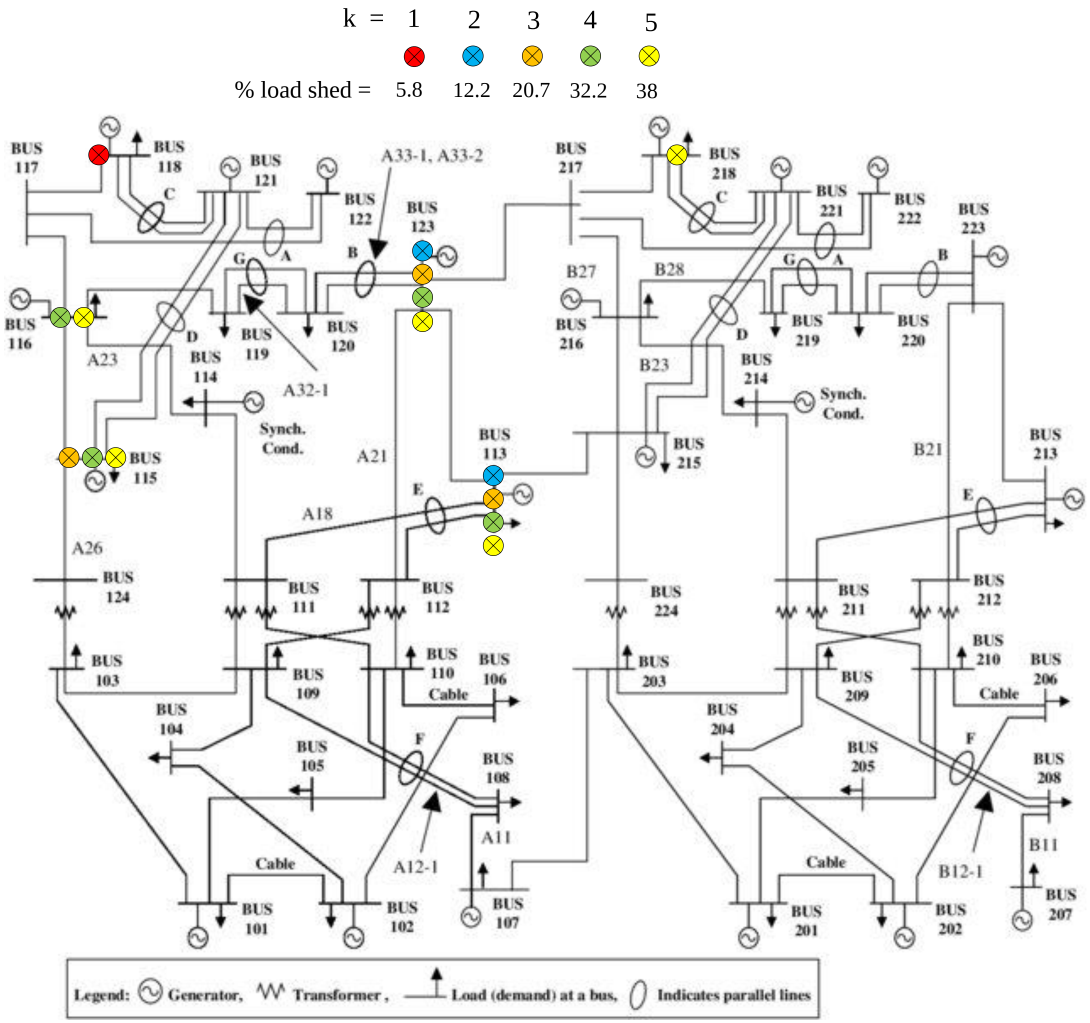
Valuable information for optimization models selecting decisions

Power System Interdiction Analysis

N-k worst-case line trips

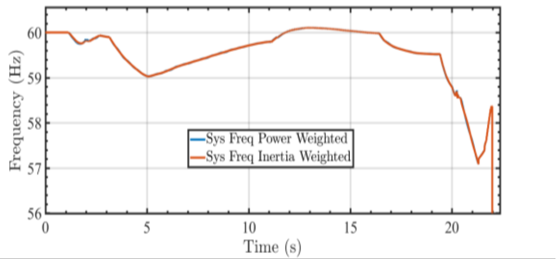


N-k worst-case bus outages



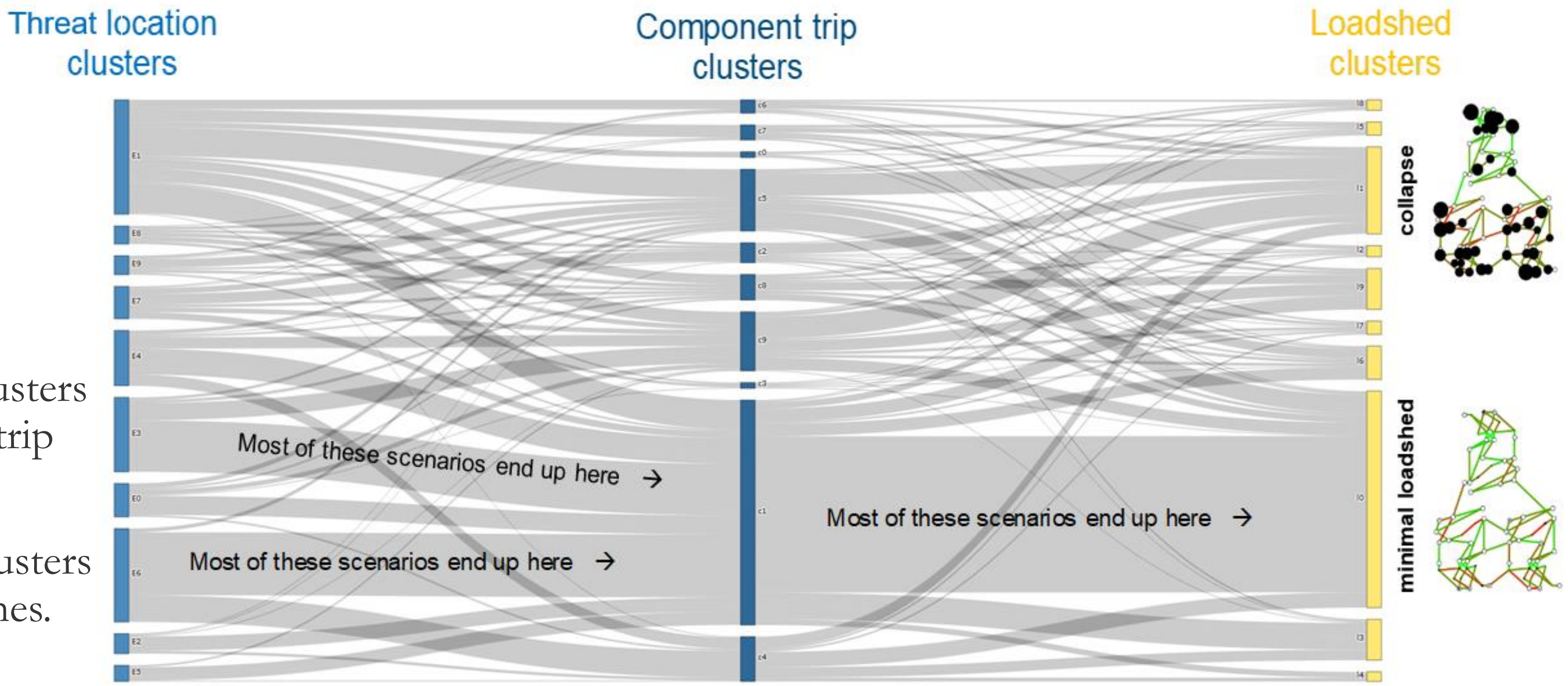
Power System Dynamics Simulations
Identify trends and clusters

- Run thousands of dynamic simulations.



- Analyze cumulative results
- Certain threat locations clusters lead to certain component trip clusters
- Certain component trip clusters lead to specific grid outcomes.

➢Overall goal: identify critical nodes and vulnerable nodes



Conclusion

- The presented optimization models can identify the optimal investments to improve resilience and/or reliability.
- Grid reliability optimization models:
  - Optimal small-scale investments can greatly improve grid reliability from a proactive approach.
- Grid resilience optimization models:
  - Hardening a specific few optimal components can greatly increase grid resilience to a regional threat.
  - Optimal preemptive action (e.g. generator dispatch or flood wall placement) can significantly improve grid resilience.
  - Optimal decisions throughout a multi-time period restoration process will improve resilience (e.g. generator dispatch and transmission switching)
- Decisions to improve resilience, need to account for initial transients and cascading failures.
- If decisions are based solely on steady-state power flows, the decisions may not address the cascading failures, which are often the worst-case contingencies.
- Identifying critical nodes and vulnerable nodes can increase system awareness and improve decision making processes.

Future Work

- Employ these models with partner utilities to make real decisions
- Expand the objectives from reliability and resilience to include other grid planning goals such as decarbonization and energy equity.
- Attempt a full three-stage grid resilience optimization model
- Continue to increase scalability of optimization models
- Add additional features to each stage of optimization models (e.g. preemptive resource placement)
- Employ these models with existing grid planning tools

Awards, Publications, & Presentations

Sandia National Laboratories

Awards

1. B. J. Pierre awarded The 2020 IEEE Albuquerque Section Outstanding Young Engineer award for “for the development of algorithms and software tools to co-optimize grid resilience and reliability.”

Peer Reviewed Journal and Conference papers

1. S. Raja, B. Arguello, B. J. Pierre, “Dynamic Programming Method to Optimally Select Power Distribution System Reliability Upgrades,” *IEEE Open Access Journal of Power and Energy*, vol. 8, pp. 118-127, Feb. 2021.
2. K. Garifi, E. Johnson, B. Arguello, B. J. Pierre, “Transmission Grid Resiliency Investment Optimization Model with SOCP Recovery Planning,” under 2nd round of revise/resubmit *IEEE transactions on Power Systems*, 2021.
3. E. Johnson, S. Ahmed, S. Dey, JP Watson, “A K-Nearest Neighbor Heuristic for Real-Time DC Optimal Transmission Switching,” submitted to *IEEE transactions on Power Systems*, 2021.
4. B. J. Pierre, B. Arguello, M. J. Garcia, “Optimal Investments to Improve Resilience Considering Initial Transient Response and Long-term Impacts,” Proceedings IEEE Probabilistic Methods Applied to Power Systems (PMAPS), Aug. 2020.
5. B. J. Pierre, B. Arguello, “Investment Optimization to Improve Power Distribution System Reliability Metrics,” Proceedings IEEE Power & Energy Society General Meeting, Aug. 2018.
6. B. J. Pierre, B. Arguello, A. Staid, R. T. Guttromson, “Investment Optimization to Improve Power System Resilience,” Proceedings IEEE Probabilistic Methods Applied to Power Systems (PMAPS), June 2018.

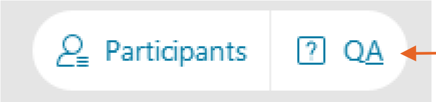
Invited Panels and Presentations (not duplicating publication presentations)

1. B. J. Pierre, “Planning and Investing for a Resilient Grid,” Accepted Panel Session Chair, Innovative Smart Grid Technologies North America (ISGT NA), Feb. 2020.
2. B. J. Pierre, “Co-optimization to Integrate Power System Reliability Decisions with Resiliency Decisions,” Presentation, Innovative Smart Grid Technologies North America (ISGT NA), Feb. 2020
3. B. J. Pierre, “Co-optimizing Investment Decisions for Electric Grid Resilience and Reliability,” Invited talk to INFORMS. 2020.
4. B. J. Pierre, “Co-optimization to Integrate Power System Reliability Decisions with Resiliency Decisions,” Invited Science & Society Distinguished Public Talks, UNM Chapter of Sigma Xi and the Albuquerque Section of IEEE, 2021.
5. B. J. Pierre, “Co-optimization to Integrate Power System Reliability Decisions with Resiliency Decisions,” Invited Talk: Energy & Earth Systems Symposium, 2019.

Discussion and Q&A

WebEx Tip

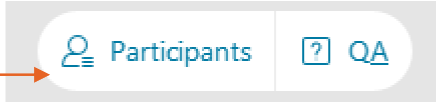
Option 1:



Access the written Q&A panel here

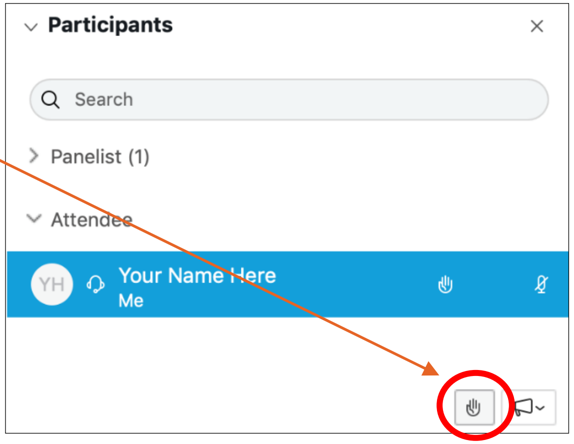
Option 2:

1. Click here to access the attendee list to raise and lower your hand.



2. Raise your hand by clicking the hand icon.

3. Lower it by clicking again.



Questions?

Dr. Brian J. Pierre

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Sandia National Laboratories

Albuquerque, NM, USA

ENERGY TECHNOLOGIES AREA

LAWRENCE BERKELEY NATIONAL LABORATORY

Risk-controlled Expansion PlAnning with dIstributed Resources (REPAIR)

June 3rd , 2021

Miguel Heleno
Lawrence Berkeley National Laboratory
miguelheleno@lbl.gov

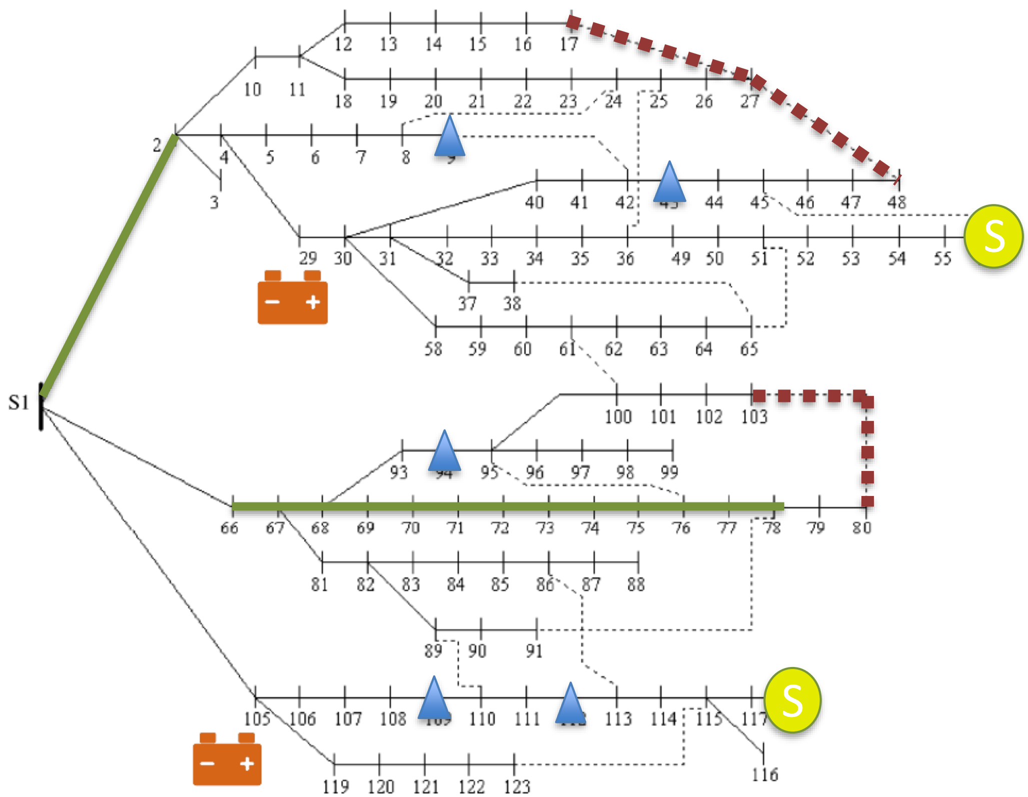
Team: A. M. Silva, A. Valenzuela, J.Eto

BERKELEY LAB

ENERGY TECHNOLOGIES AREA

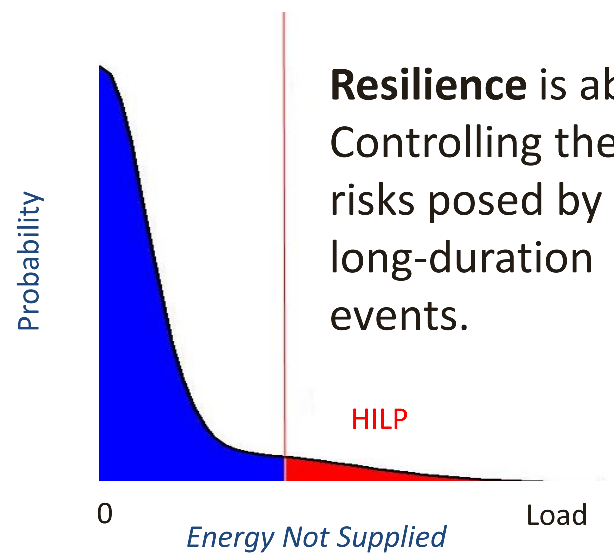
Expansion and planning problems: Reliability vs Resilience

- Optimal Investment problems constrained by security criteria.



Reliability is about controlling the risk of routine, short-duration events:

- Frequency (SAIFI)
- Duration (SAIDI)



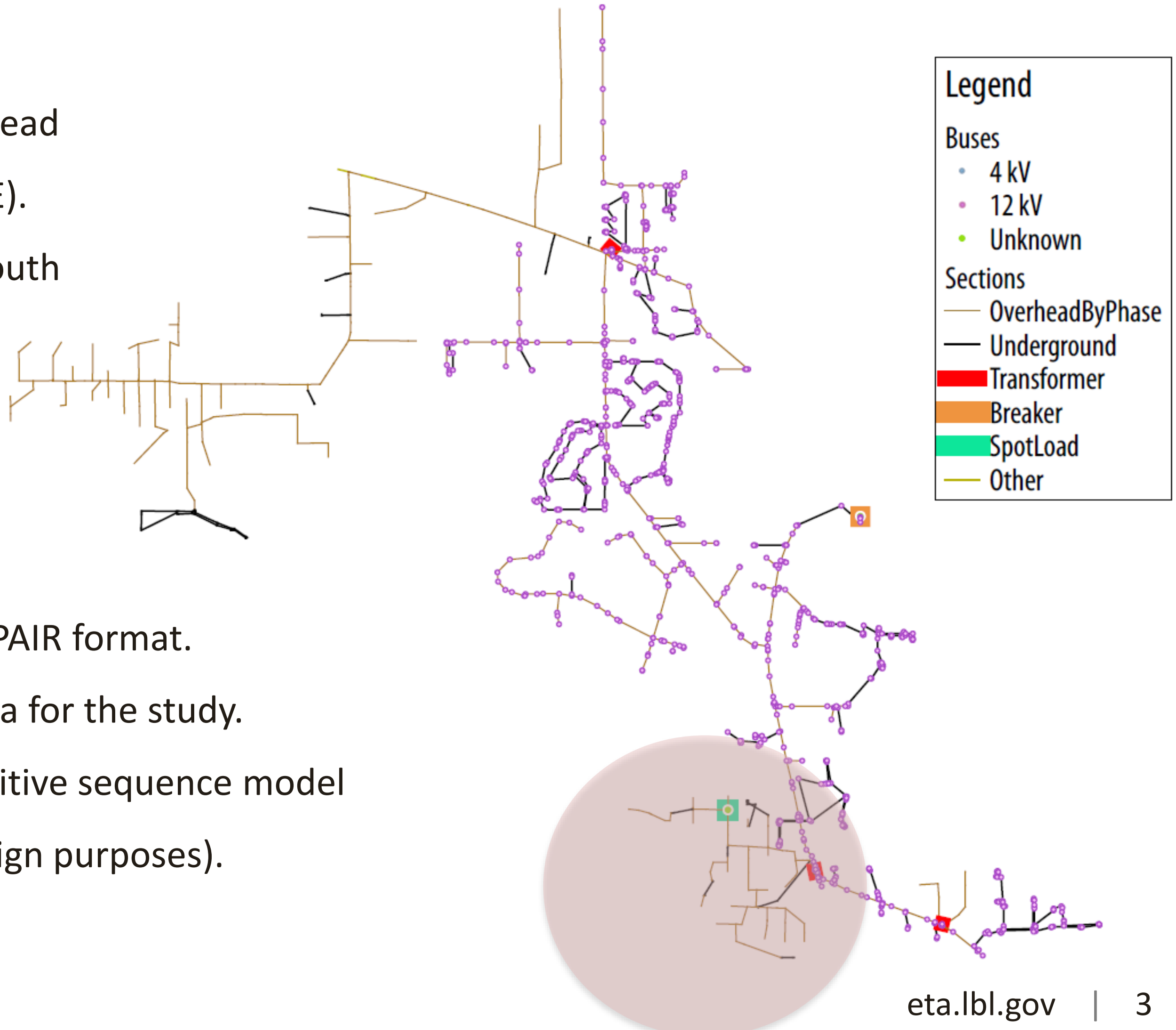
Resilience is about Controlling the risks posed by rare, long-duration events.

What are the trade-offs??

Example

Feeder:

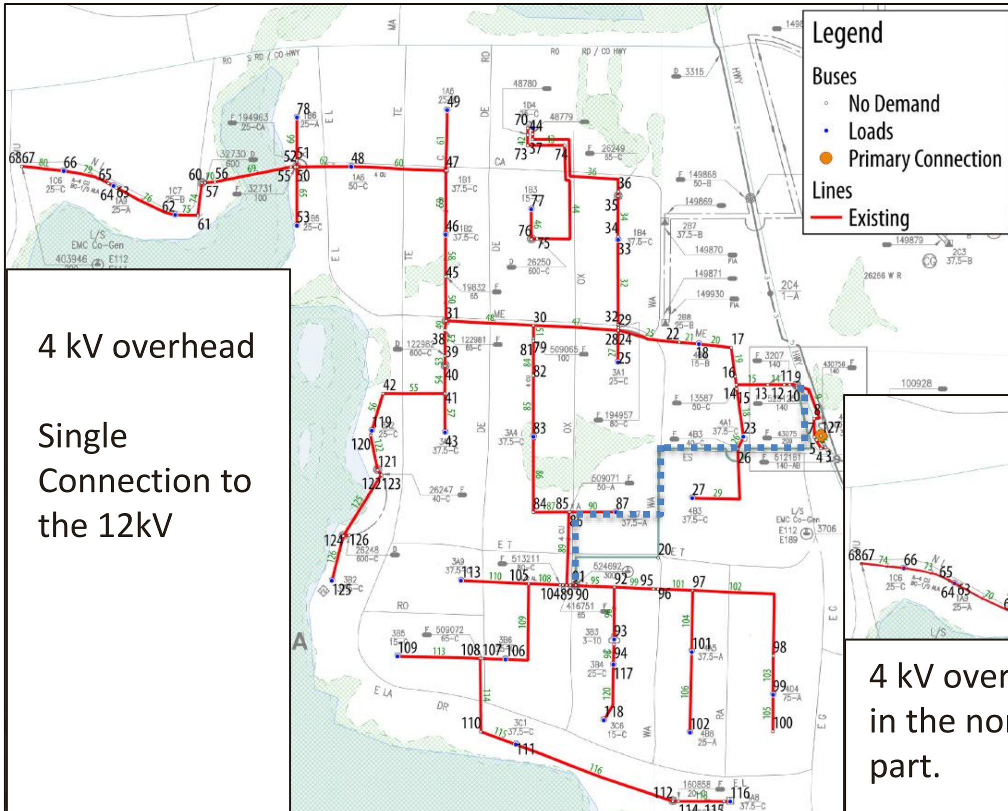
- 12 kV and 4 kV Overhead
- 3 phase model (CYME).
- Area of study 4kV - south



Data Processing

- Conversion to the REPAIR format.
- Isolate the feeder area for the study.
- Approximate to a positive sequence model (for planning and design purposes).

System Plan: Original, Intermediate and Final System



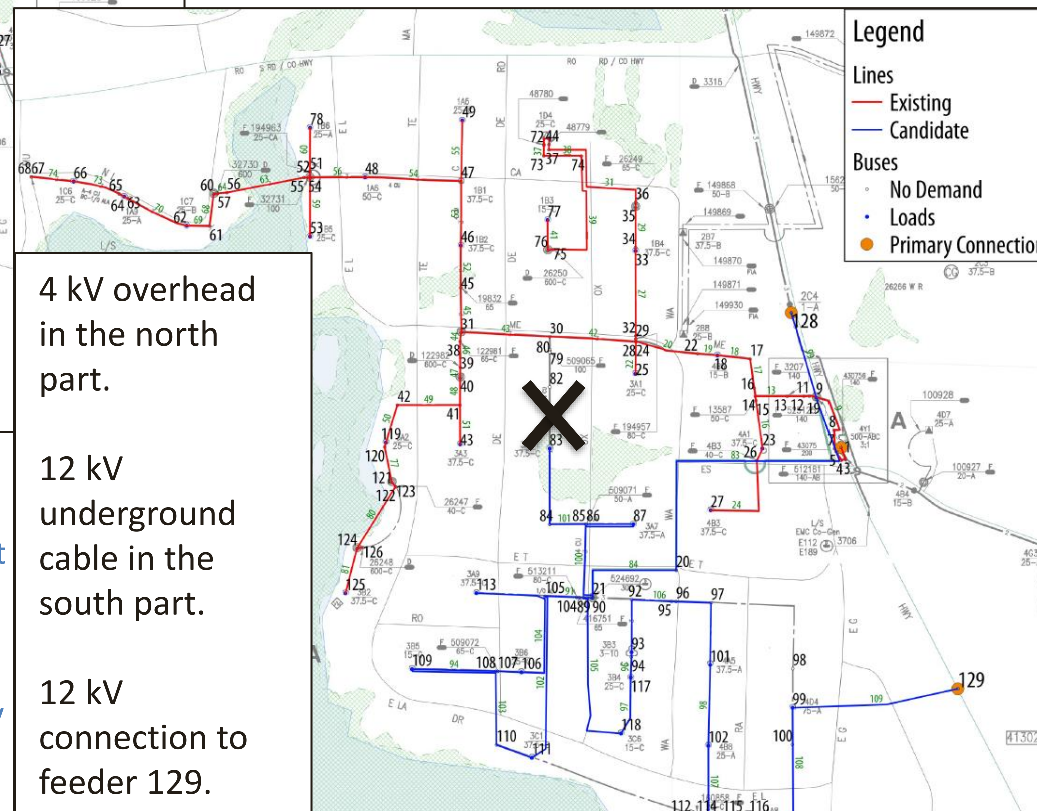
4 kV overhead

Single Connection to the 12kV

Intermediate Plan

Reliability Investment (increasing redundancy)

new connection between north and south



4 kV overhead in the north part.

12 kV underground cable in the south part.

12 kV connection to feeder 129.

Final Plan

Resilience Investment

Hardening the south part of the feeder + connecting to a 12 kV loop

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ENERGY TECHNOLOGIES AREA

Inputs - Outage Data

Data Received

- Outage data was received in an html format.
- 10 years of routine outage data.
- Outage data for the entire feeder.

Data Processing

- Conversion to a CSV format.
- Isolate outages on the area of study.
- Events converted to a rate of failure.

lat	lng	pin_info	zIndex	CAUSE	CAUSE_DE	DAMAGE	DEVICE_TYPE	FEEDER_L	KV	MATERIAL_INVOLVED	METER_CNT	MSTR_TKT_NO	OPERATING_DEVICE	PREMISE_	START_DATETIME	STORM_IN	SYSTEM_NAME	SectionID
42.26027	-88.1583	TYPE	10	PUBLIC DA	VEHICLE (I	BROKEN	FUSE	N	12	POLE	240	1791832	403263Y1	234	1/11/2009 2	0	OVERHEAD	189846834
42.26304	-88.1566	TYPE	10	WEATHER	ICE/SNOW	BROKEN	FUSE	N	12	FUSE	43	1834045	124974	43	3/29/2009 12	-1	OVERHEAD	174709131
42.253	-88.1818	TYPE	10	TREE/VEG	UPROOTEI	WIRE DOV	FUSE	N	4	PHASE WIRE (ALL VOLTAGES)	5	1834057	81417	5	3/29/2009 12	-1	OVERHEAD	39576116
42.25477	-88.1904	TYPE	10	WEATHER	ICE/SNOW	WIRE DOV	FUSE	N	4	CABLE-AERIAL	9	1834351	8339	9	3/29/2009 2	-1	OVERHEAD	86218049
42.25644	-88.1586	TYPE	10	WEATHER	ICE/SNOW	BROKEN	FUSE	N	12	POLE	1	1836011	403263B9	1	3/30/2009 11	0	OVERHEAD	177424175
42.26304	-88.1566	TYPE	10	UNKNOW	UNDETERI	BROKEN	FUSE	N	12	FUSE	43	1837258	124974	43	4/1/2009 7	0	OVERHEAD	174709131

Assumptions

- Conductors with N failures were assumed to have a N/10 annual rate of failure.
- Conductors with 0 failures and new connections were assumed to have a 1/10 annual rate of failures.

rate of failure	# lines
0.1	122
0.2	0
0.3	3
0.4	1
>=0.5	1
Total	127

Critical Scenarios

Storm events

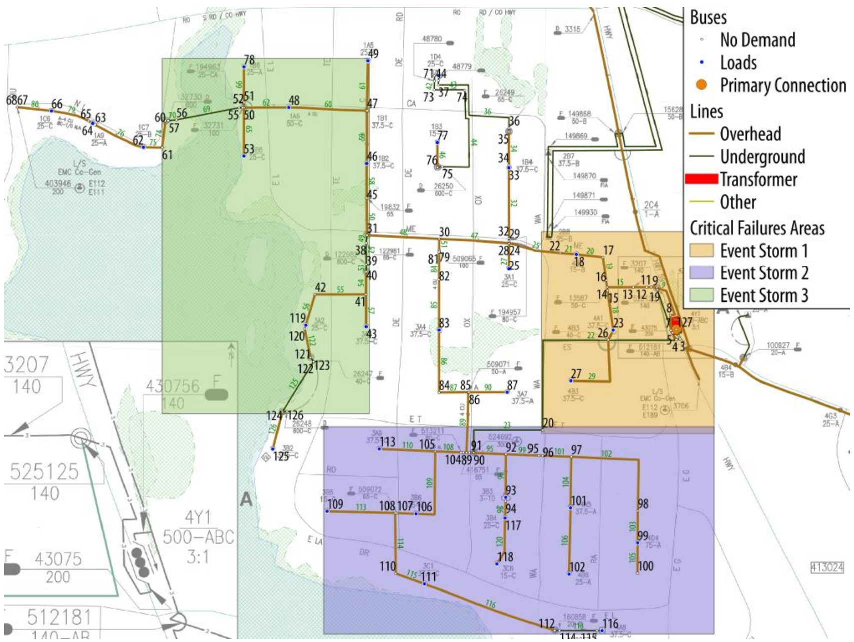
4 types of storm events that can hit different areas of the network.

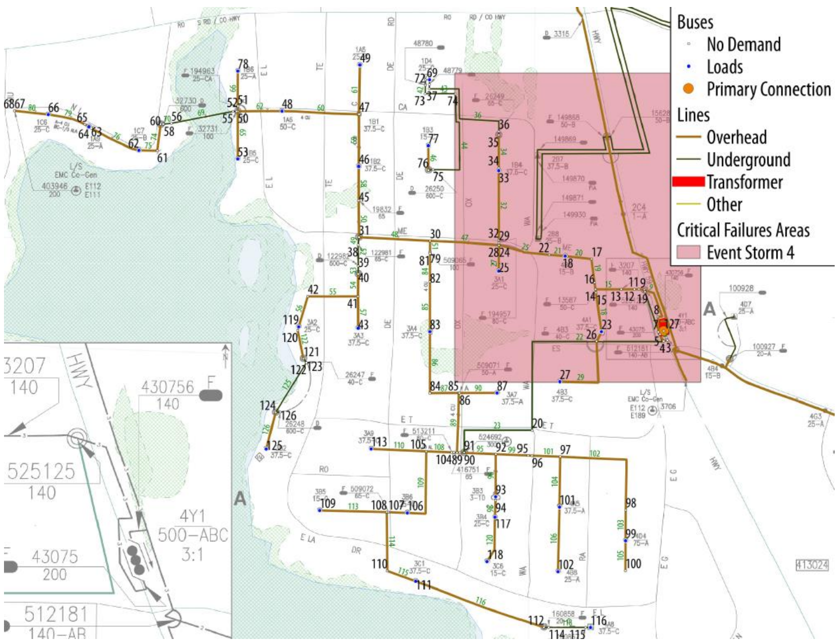
Event Consequences

Damage all overhead lines in the area.

Frequency

Each event is assumed to take place 1/70 years.





Critical Scenarios

Flood events

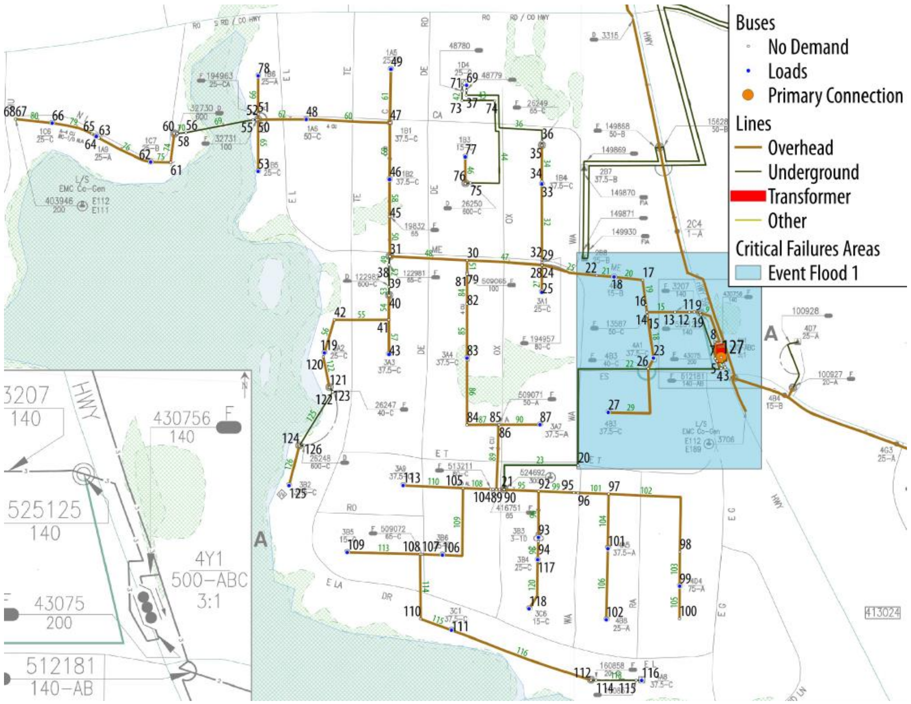
2 types of flood that can hit the central area of the network.

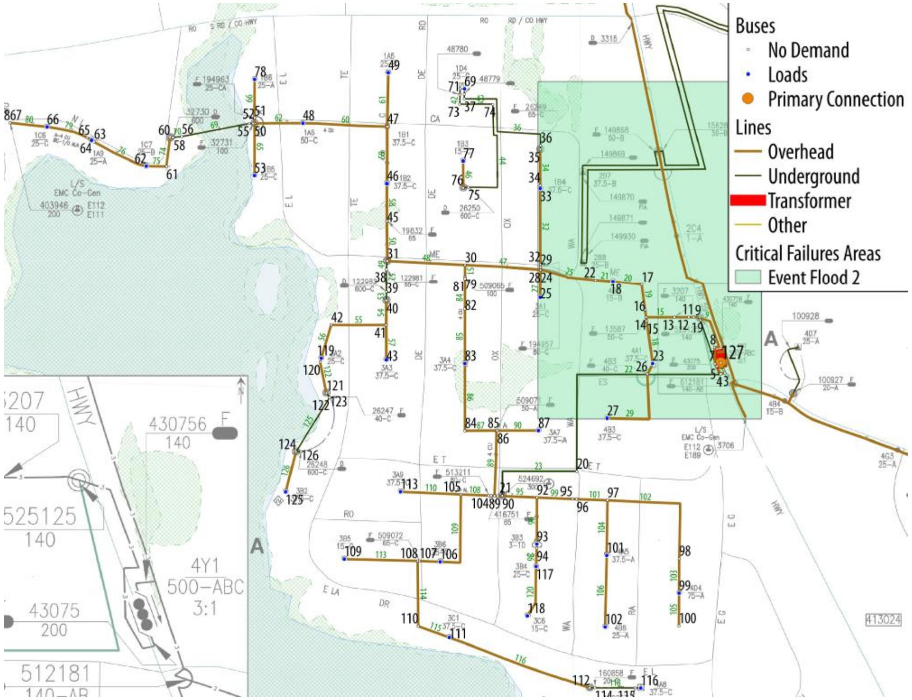
Event Consequences

Damage all underground cables located in the areas.

Frequency

Each event is assumed to take place 1/70 years.





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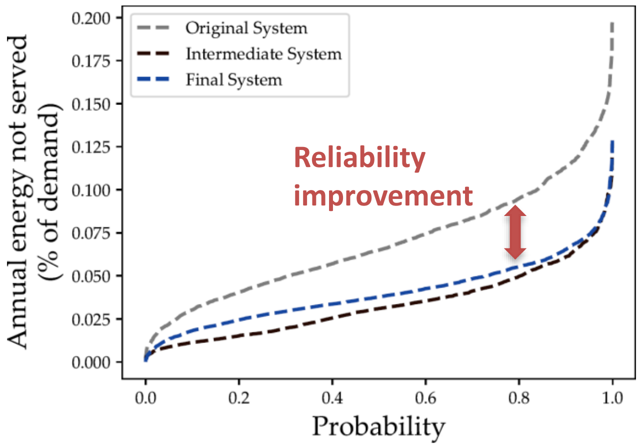
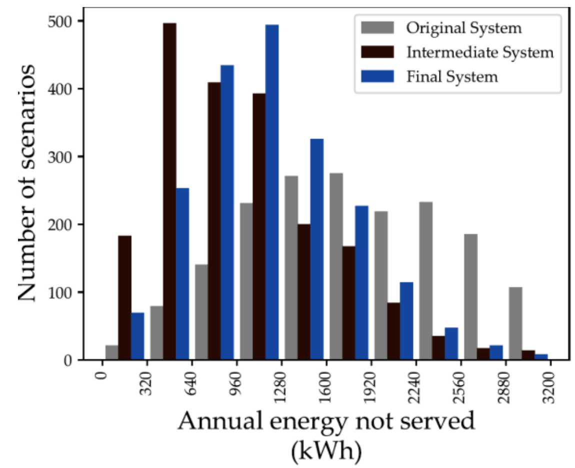
ENERGY TECHNOLOGIES AREA

Reliability Results

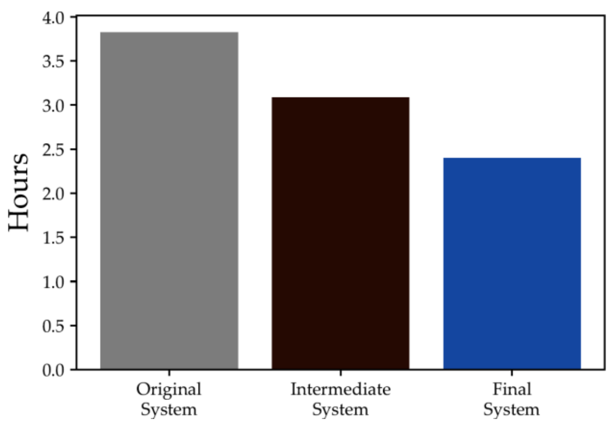
AENS – cumulative distribution



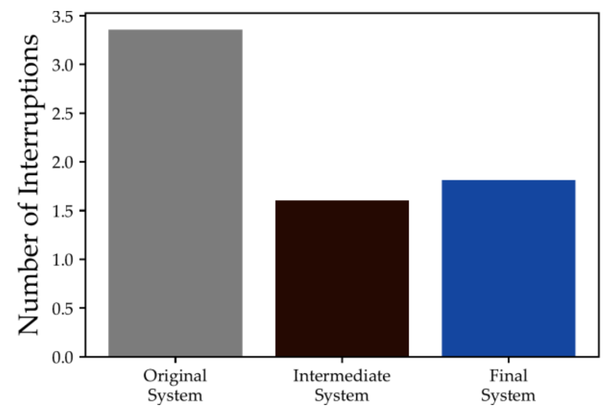
AENS – distribution



SAIDI

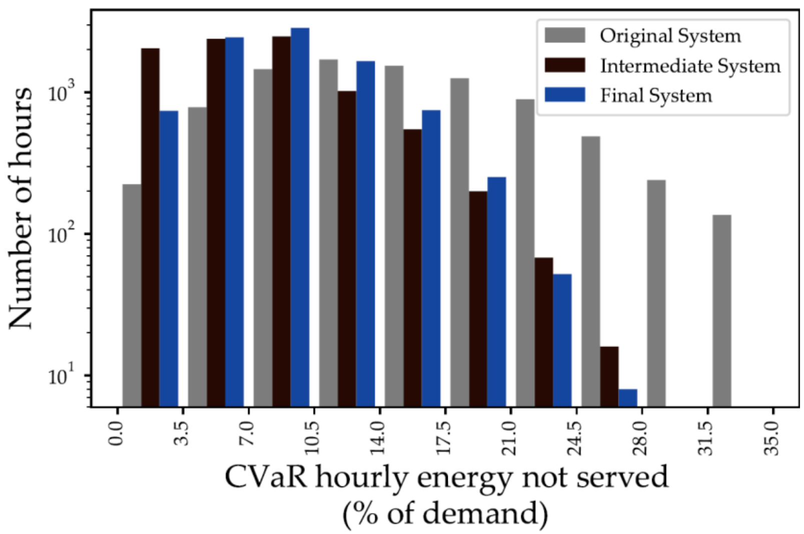


SAIFI

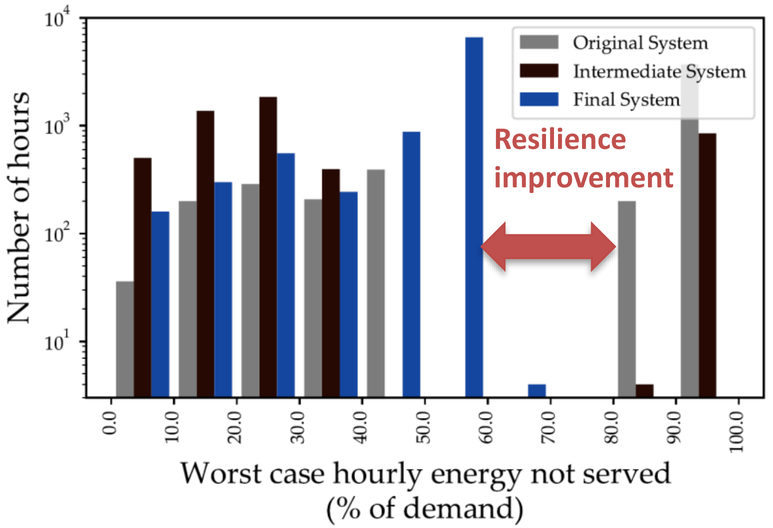


Resilience Results

CVaR - Risk of not serving demand



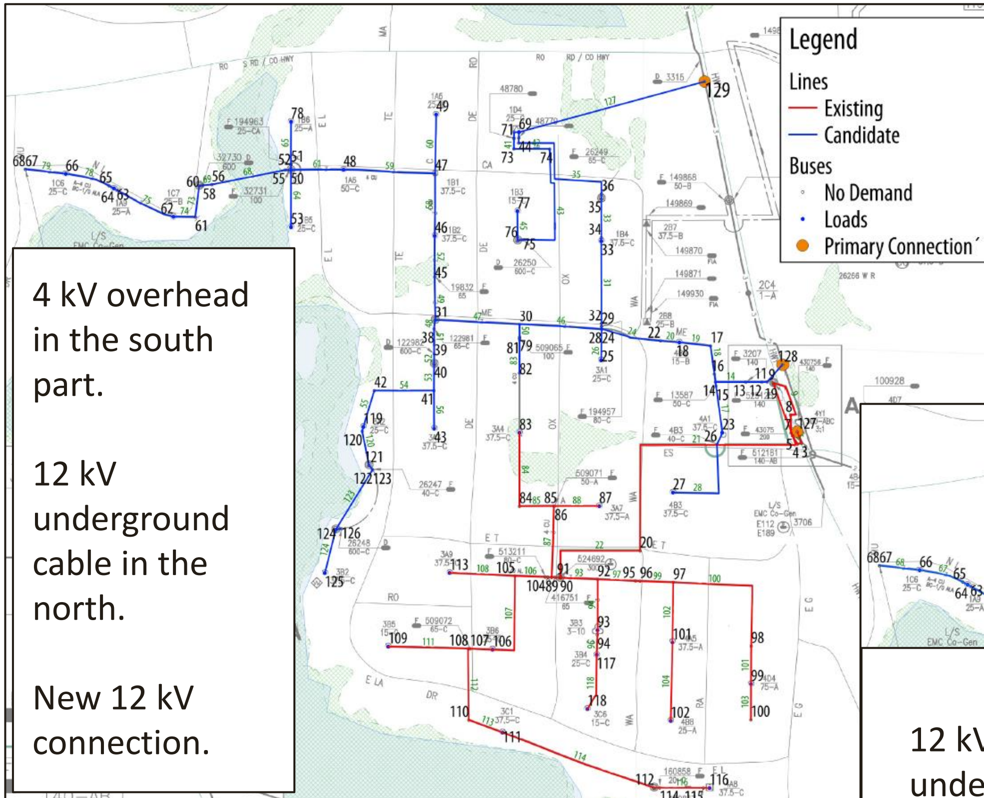
Worst case evaluation



Conclusions

- The planned investments made the infrastructure slightly less reliable in terms of frequency of interruptions but improved the resilience of the system.
- Reliability investments are not the same as Resilience investments. A trade-off exists when planning grid assets.

Two additional Plans: North Plan, Combined Plan



4 kV overhead in the south part.

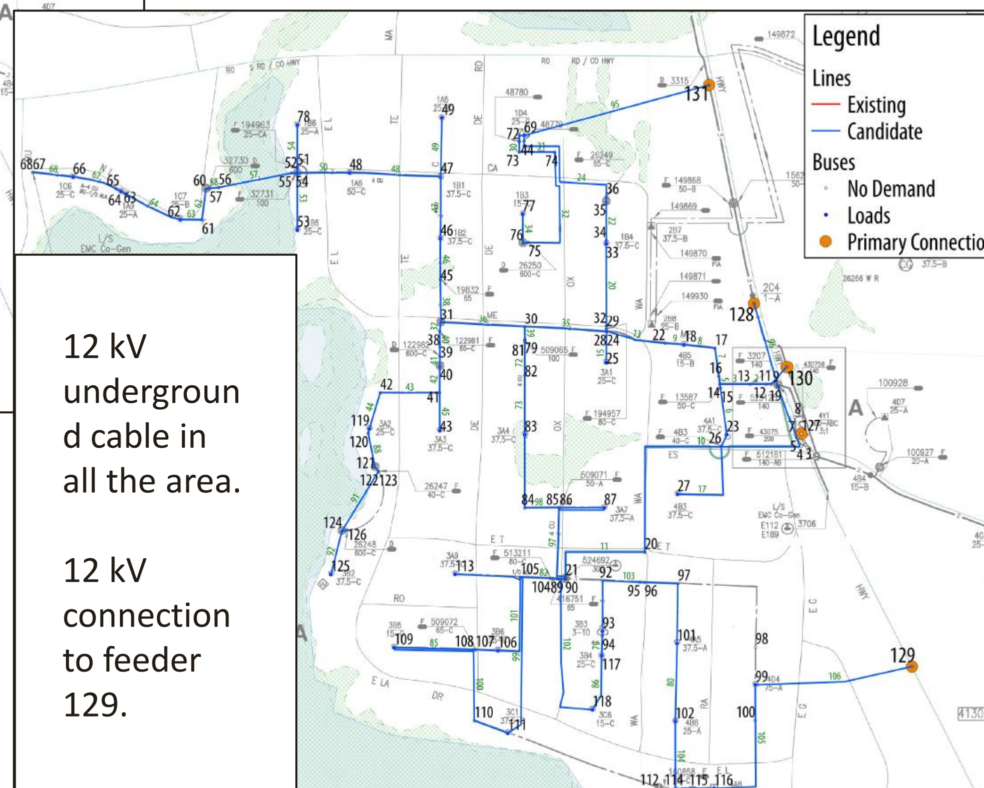
12 kV underground cable in the north.

New 12 kV connection.

North Plan

Resilience Investment

Hardening the north part of the feeder + connecting to a 12 kV loop



12 kV underground cable in all the area.

12 kV connection to feeder 129.

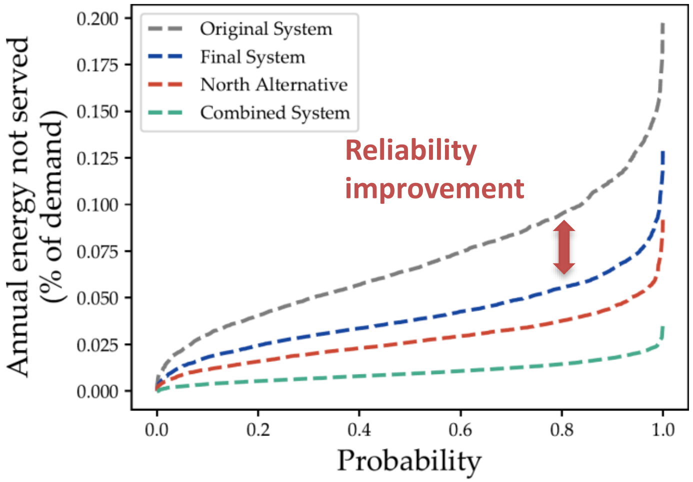
Integrated Plan

Resilience Investment

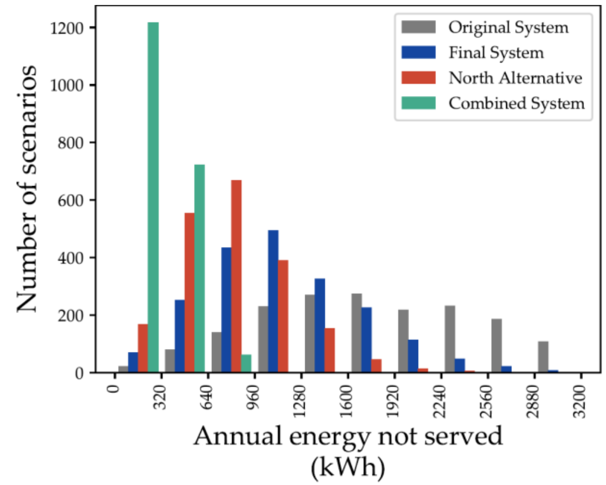
Hardening the full system and connecting to 12 kV loop

Reliability Results

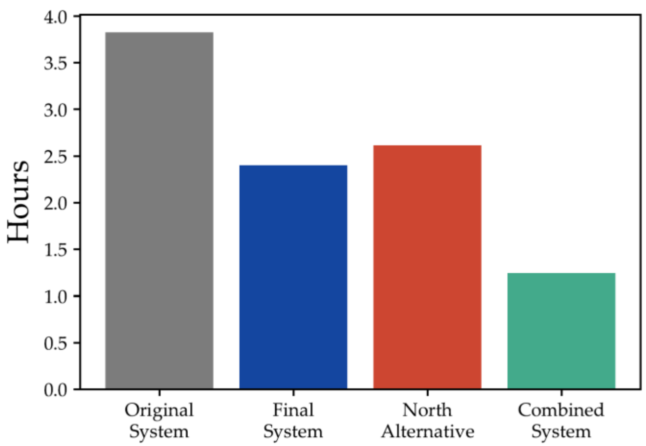
AENS – cumulative distribution



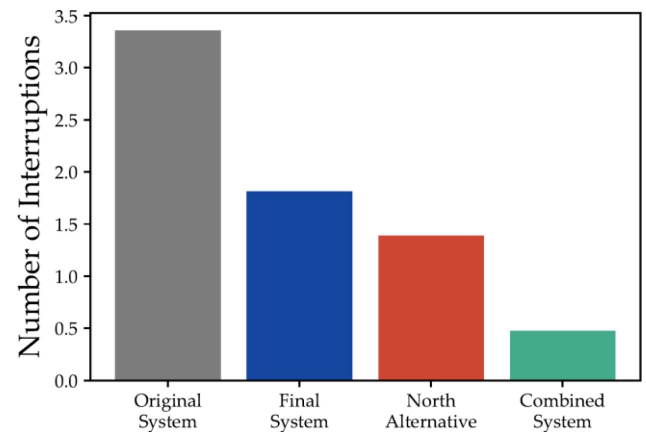
AENS – distribution



SAIDI

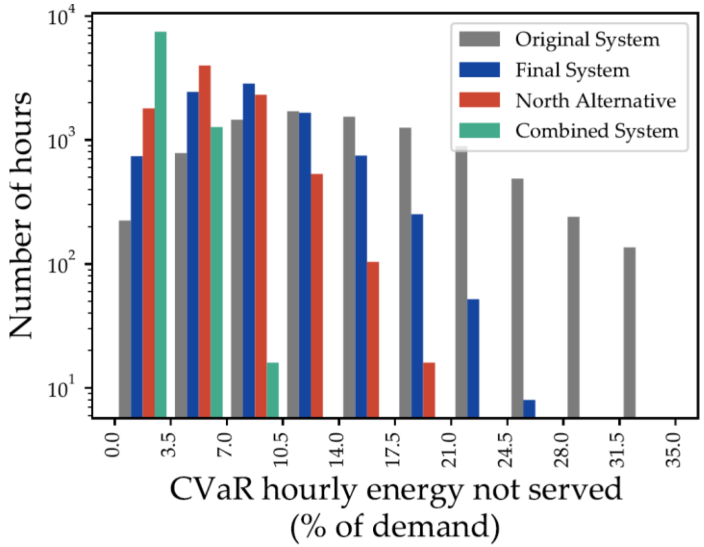


SAIFI

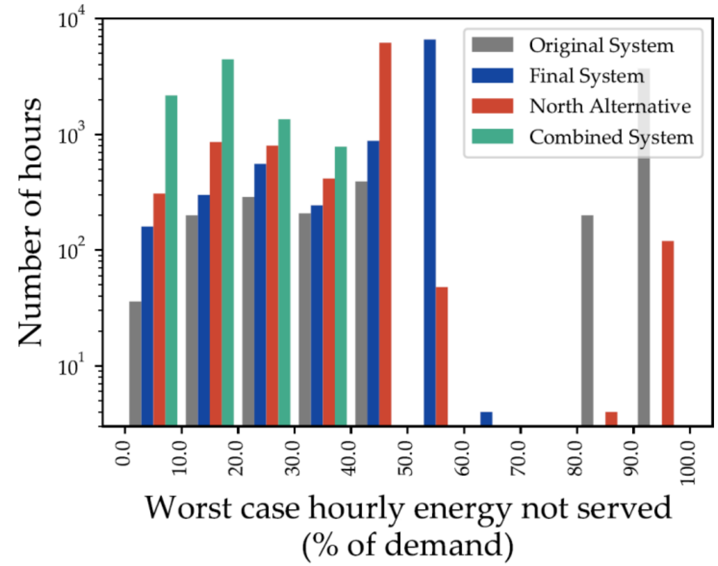


Resilience Results

CVaR - Risk of not serving demand



Worst case evaluation

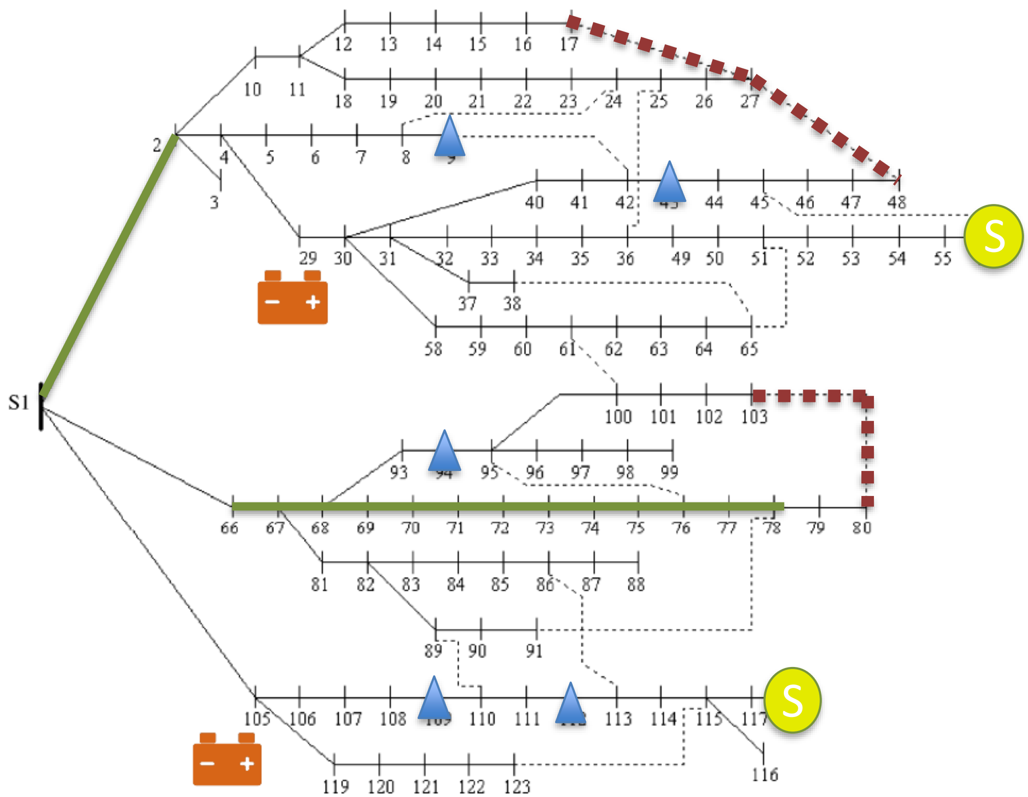


Conclusions

- The north alternative plan would be more reliable in terms of frequency of outages, but the worst option in terms of duration of outages and resilience.
- The combined plan plan was the better option, but it was significantly more expensive.
- <u>We need tools able to support this decisions and to explore this trade-offs.</u>

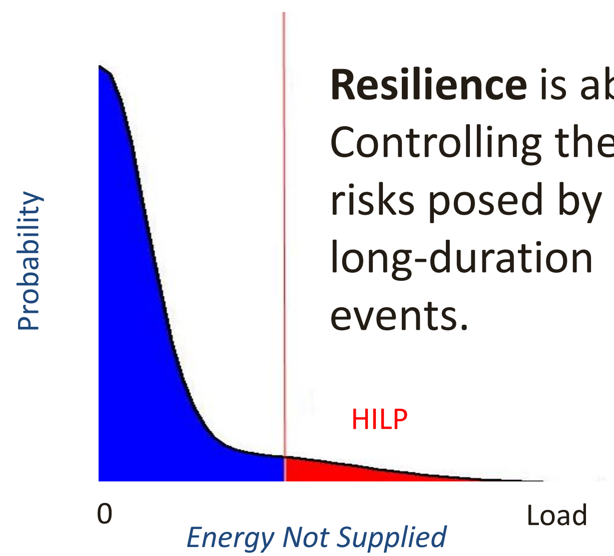
Expansion and planning problems: Reliability vs Resilience

- Optimal Investment problems constrained by security criteria.



Reliability is about controlling the risk of routine, short-duration events:

- Frequency (SAIFI)
- Duration (SAIDI)



Resilience is about Controlling the risks posed by rare, long-duration events.

How to plan considering these trade-offs??

REPAIR Methodology: adding DERs

- Cost Vs Risk Model

cost
- Investment cost
- Operation cost
- Loss of load cost

Reliability
Expected value of the outages
(Routine events)

Resilience
Conditional value at Risk of outages
(HILP events)

$$\text{Minimize}(1-\lambda)\text{E}[\text{cost}]+\lambda\text{CVaR}[\text{cost}]$$

Level of Risk Aversion considered in the **reliability vs resilience** planning exercise

St
- nodal balance constraints
- power flow constraints
- substations constraints
- **time coupling constraints For battery operation**
- **DG model and technical limits**

For each hour "t" of a typical day "d"

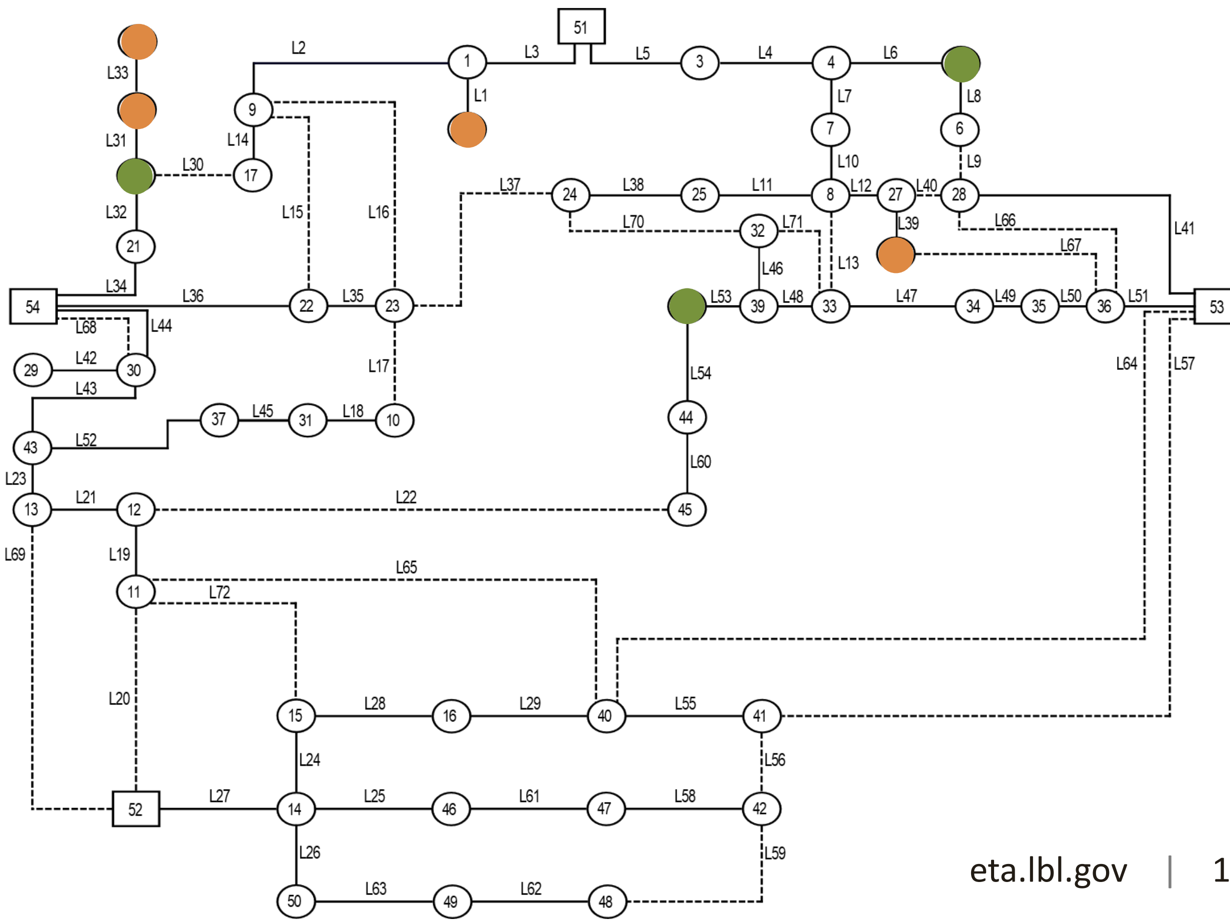
Preliminary Case Study with DERs

- Test Feeder
  - 13.5 kV
  - 54 Nodes – 50 Lines
  - 7 MW Peak
- Scenarios
  - 1263 scenarios of **routine** failures (1 every 2.5 years)
  - 100 scenarios of **HILP events** (1 every 70 years)
- Candidate Assets
  - 22 new lines
  - 4 batteries nodes
  - 4 types of DG in 3 candidate nodes.

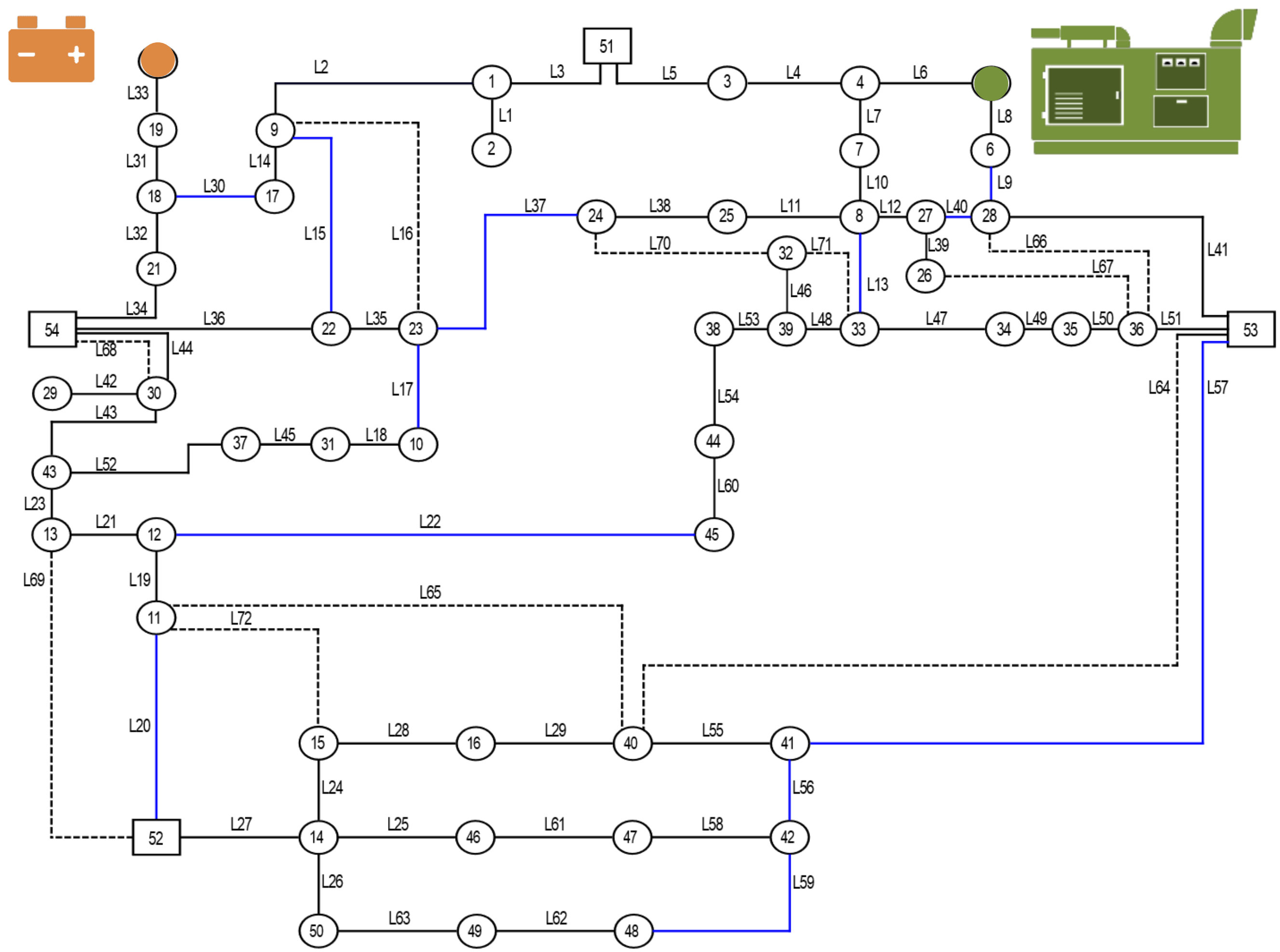
.... **New Lines**

DG nodes

Battery nodes



Without Considering Risk-aversion (λ=0) Only Reliability

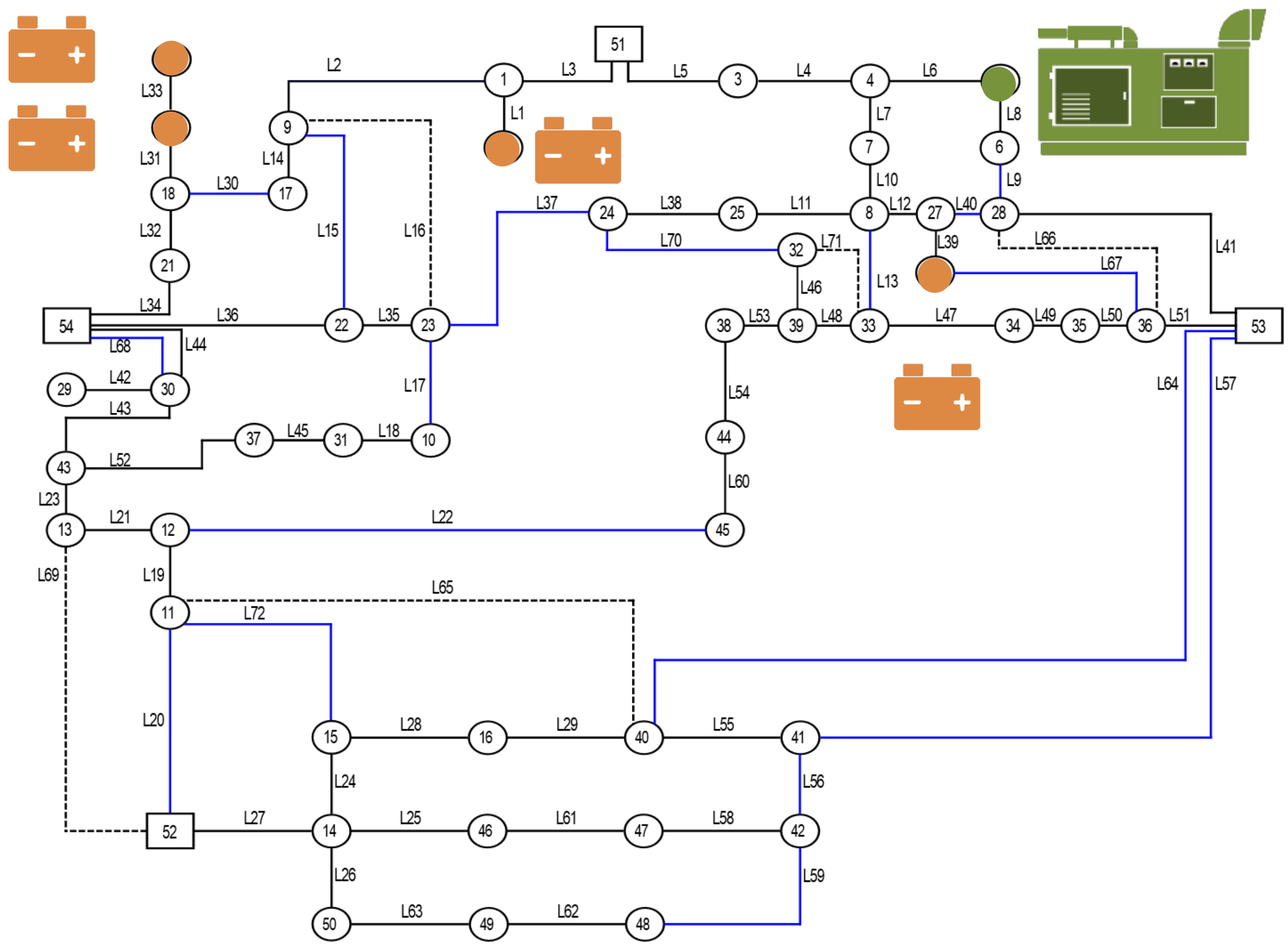


New Lines: 12

DG: 1 x 800 kW (NG)

Battery
1 x 280 kWh

Considering Risk-aversion (λ=0.5) Reliability and Resilience



New Lines: 17

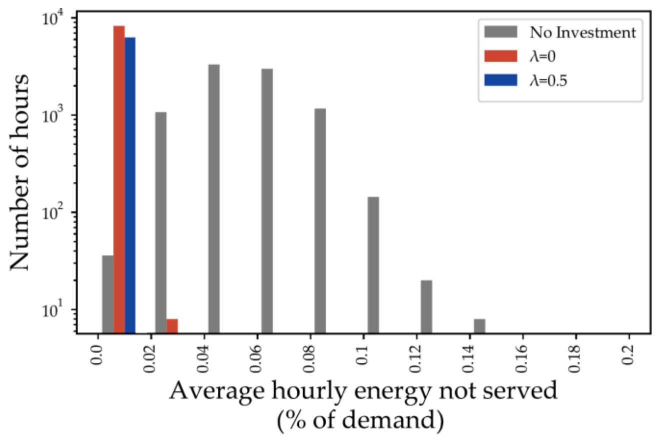
DG: 1 x 800 kW (NG)

Battery
1 x 800 kWh
1 x 360 kWh
1 x 300 kWh
1 x 500 kWh

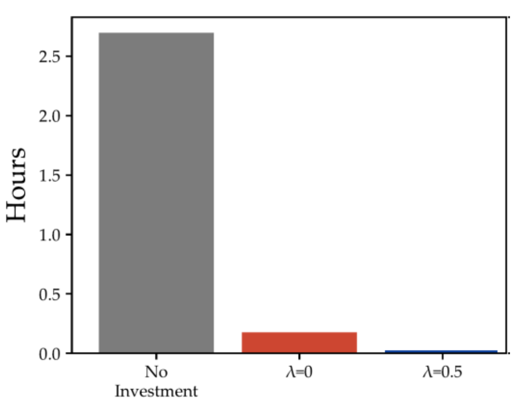
Reliability and Resilience Results

Reliability Analysis

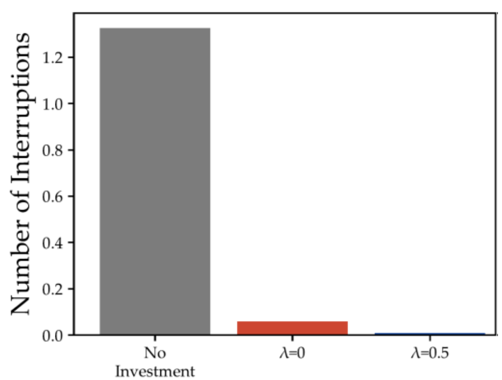
% AENS – distribution



SAIDI

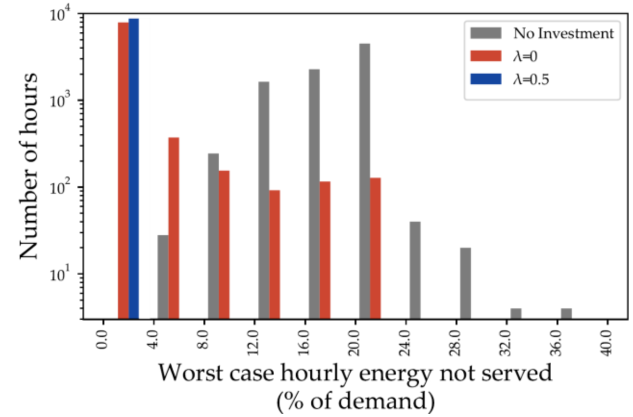


SAIFI

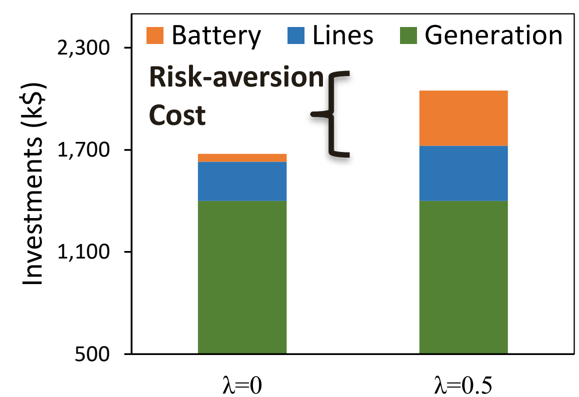


Resilience Analysis

Worst case evaluation



Investments



Next Steps

Planned developments

- Expand the type of investments (e.g. DA, microgrids)
- Capture the uncertainty of renewable energy generation.
- Accommodate part of the transmission grid expansion and planning.

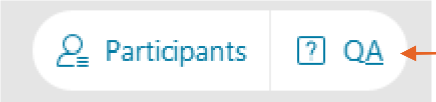
Other potential applications

- Resilience quantitative valuation model for grid assets.
- Cost vs Risk transparency model.
- Risk-based decisions in hours ahead operations (e.g. PSPS events).

Discussion and Q&A

WebEx Tip

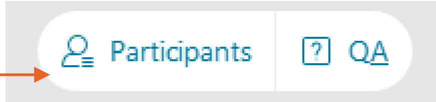
Option 1:



Access the written Q&A panel here

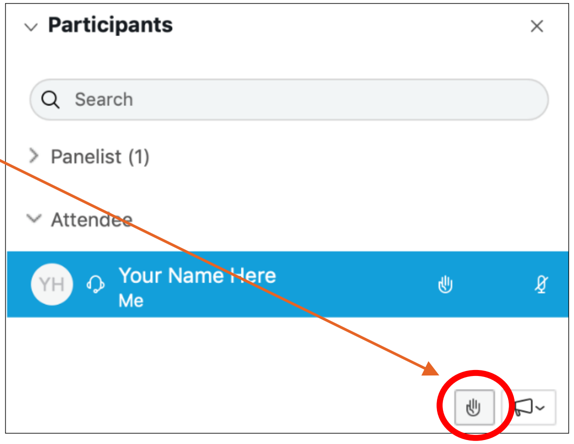
Option 2:

1. Click here to access the attendee list to raise and lower your hand.



2. Raise your hand by clicking the hand icon.

3. Lower it by clicking again.



Upcoming Meetings

- **Thursday, June 17, 2021, 2-4PM**
  Topic: Value of Resiliency – Pillar 3: Resiliency Scorecard; Sandia Labs presentation of Resiliency Node Cluster Analysis Tool

- **Thursday, July 1, 2021, 2-4PM**
  Topic: Value of Resiliency – Pillar 4: Resiliency Assessment Post-disruption; additional presentations TBD

California Public Utilities Commission

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https://www.cpuc.ca.gov/resiliencyandmicrogrids/