2020 Microgrid R&D Program Peer Review Meeting

Risk-controlled Expansion Planning with Distributed Resources (REPAIR)

Miguel Heleno

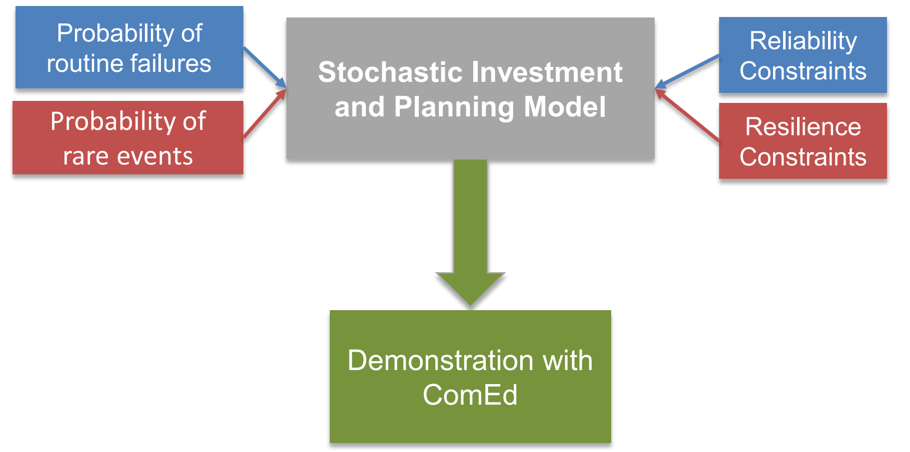
Lawrence Berkeley National Laboratory

June 10, 2020

REPAIR Project

Objectives & Outcomes

- Develop a risk-based optimization and decision-making model to address reliability and resilience at the investment and planning stage for distribution systems.
- Integrate reliability and resilience into distribution expansion and planning models.
- Demonstrate the value of a risk-based approach to the utility planning decisions.



Technical Scope

- Develop a stochastic expansion and planning model for distribution grids
- Adding reliability objectives, by modeling routine network failures and reliability costs.
- Adding resilience targets, by modeling the risk associated to High Impact Low Probability outages.
- Conduct a demonstration with a utility partner.

Funding Summary ($K)

FY19 & prior, authorized	FY20, authorized	FY21, requested
$0	$250k (+$300k AGM)	$400k (+$400k AGM)

Significance and Impact

- Industry Needs
  - The electrification of important sectors of the economy and society (health, information, industry, etc.) makes power distribution vital for communities' , which requires distribution grids to be **reliable**.

  - High Impact Low Probability Events (HILP) (such as storms, hurricanes, earthquakes, wildfires, etc.) are becoming more frequent, which requires distribution grids to be **resilient.**

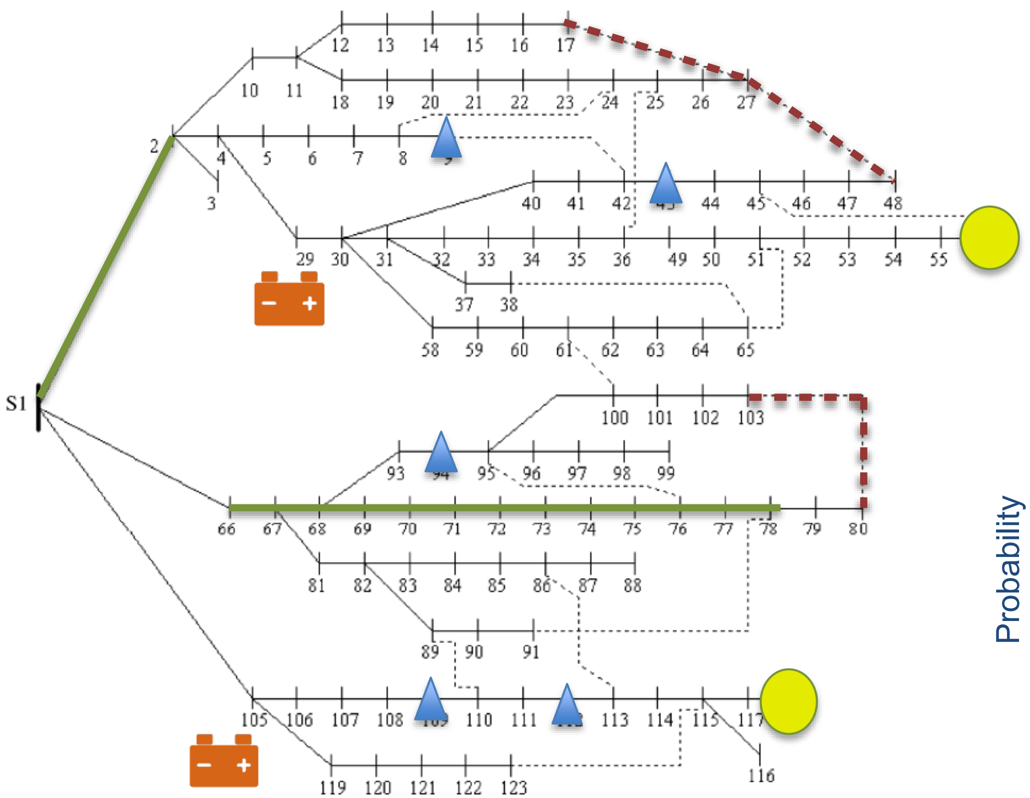
- Technical Planning Problem
  - How to make sure utilities have the necessary resources on the ground to respond to routine failures and mitigate the HILP events?
  - How can utilities make risk informed decisions when planning for investments?
  - What are the trade-offs between optimizing for Economic, Reliability and Resilience targets?

Significance and Impact

- Project Objectives
  - The Risk-controlled Expansion PlAnning with dIstributed Resources (REPAIR) project is building a foundational modeling framework to enable risk-controlled decisions in utility grid planning to prevent and mitigate the impact of outages caused by **routine equipment failures or by High Impact Low Probability events**, such as storms, earthquakes or wildfires that my cause longer interruptions of service;
  - Offers an innovative **risk-based optimization and decision-making model** to help utilities reducing the vulnerability of local communities to HILP events and protect critical infrastructures;
  - Aims to build a software tool to support **strategic planning decisions** around reliability and resilience that combine investments in DERs with grid reinforcement, in order to reduce the magnitude and duration of short- and long-term outages.
- Main Outcomes
  - Integrate reliability and resilience into power distribution grid planning;
  - Cost vs Risk models to support utility planning decisions around reliability and resilience;
  - Proof of concept in partnership with ComEd.

Approach: Addressing Reliability and Resilience

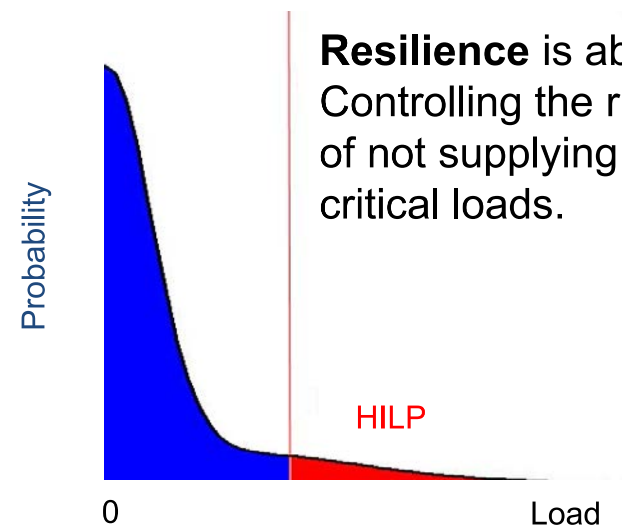
- Concept Clarification
  - While reliability has standard definition and metrics, different approaches exist to define power distribution resilience. In REPAIR project, we define resilience planning as the ability to reduce the risk of outages associated with HILP events.



Reliability is about controlling the expected value of the load not supplied:

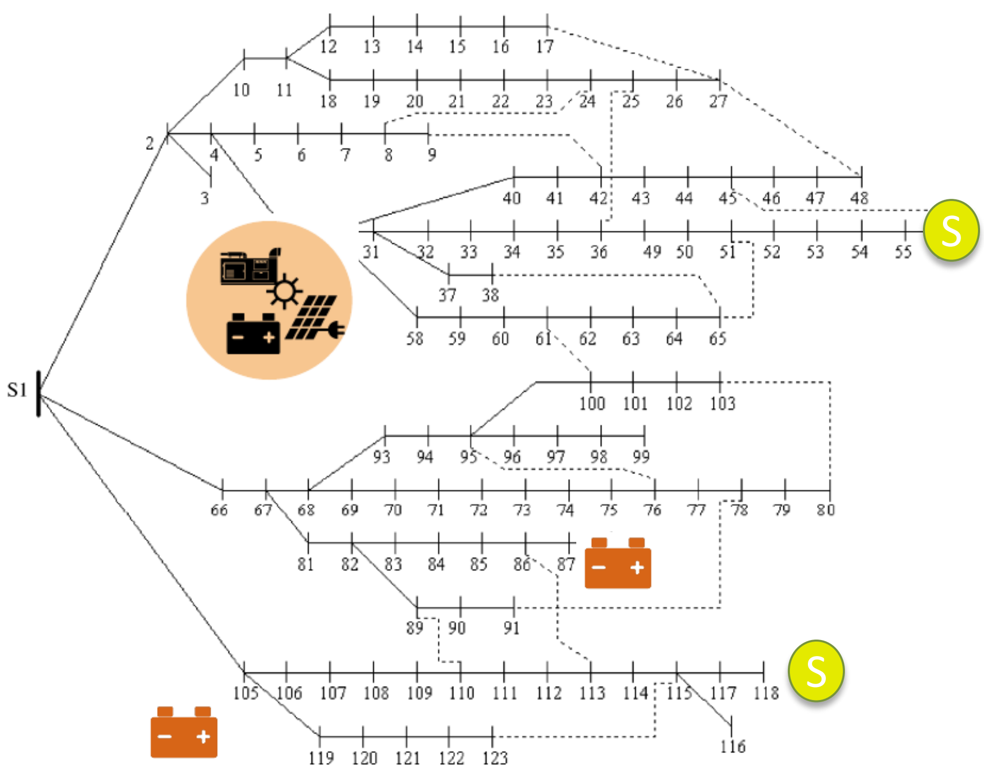
- Frequency (SAIFI)
- Duration (SAIDI)

Resilience is about Controlling the risk of not supplying critical loads.



Approach: Addressing Reliability and Resilience

- Practical Implications in Grid Expansion and Planning Problem:



New connections to the transmission system: **Improves reliability.**

HILP Events:

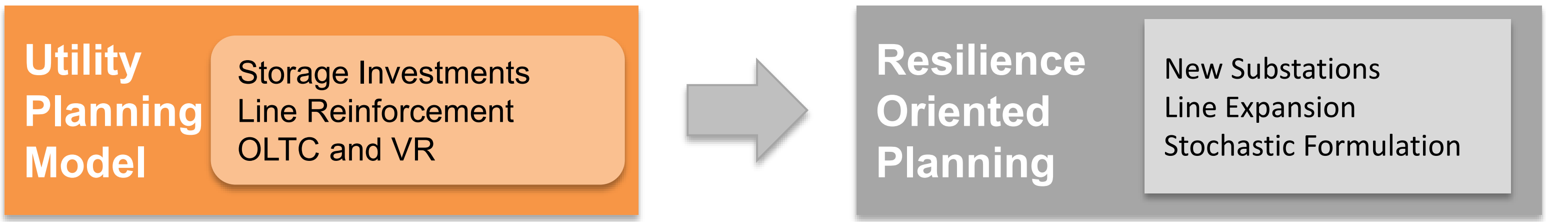
- A storms affects the transmission system
- An earthquake affects the substation structure.

Installing storage close to critical loads is a better solution to **improve resiliency**.

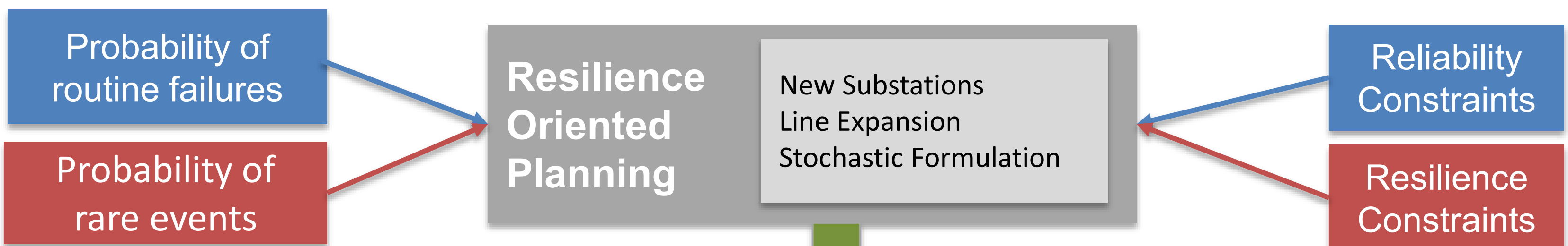
What is the Trade-off?

Methodology Overview

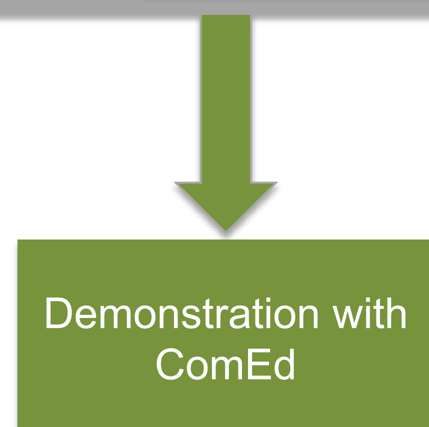
- Expanding Utility Planning Model to also consider resilience investments:



- Introduce Reliability and Resilience criteria into the planning problem:

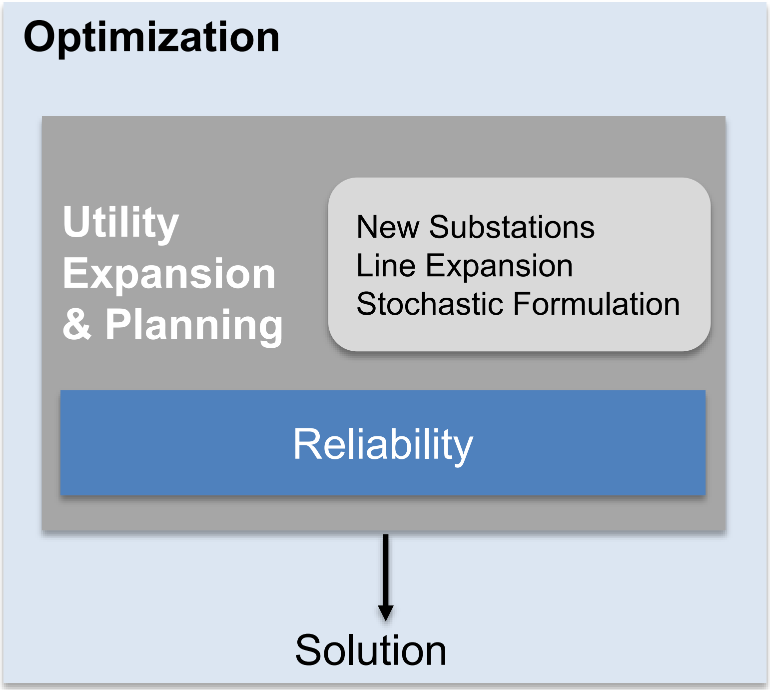


- Proof of Concept:



Modeling Reliability

- Adding reliability constraints to the expansion and planning model:

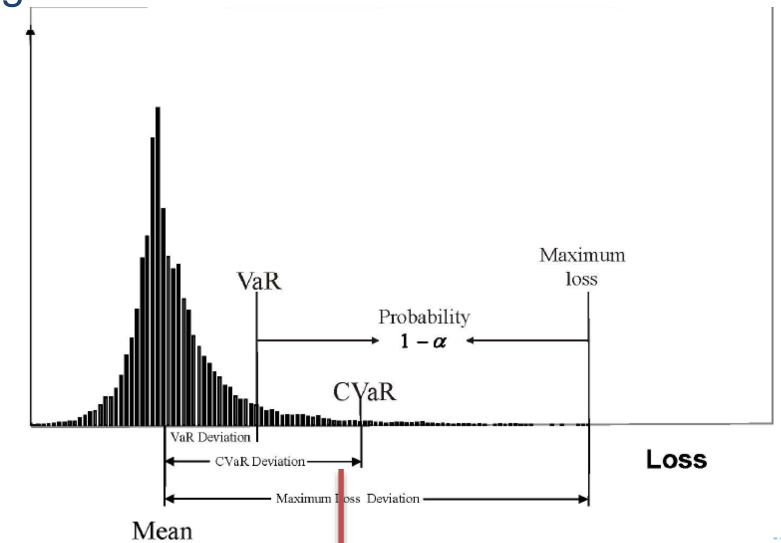


Reliability is explicitly included in the expansion and planning optimization model by considering the expected value of loss of load in the different nodes of the network.

Historical data **regarding component routine failures** is considered to build a probabilistic model of network interruptions.

Modeling Resilience

- Adding resilience to the expansion and planning model:
  - A metric used in financial mathematics to mitigate losses associated with HILP events is the **Conditional Value at Risk (CVaR)**, also called Expected shortfall.
  - CVaR can capture the tail events and has good mathematical proprieties that allows it to be used in linear programming.



Utility Expansion & Planning

New Substations
Line Expansion
Stochastic Formulation

Adding CVaR constraints

Model Overview

- Cost Vs Risk Model

cost { Investment cost, Operation cost, Loss of load cost }

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

St

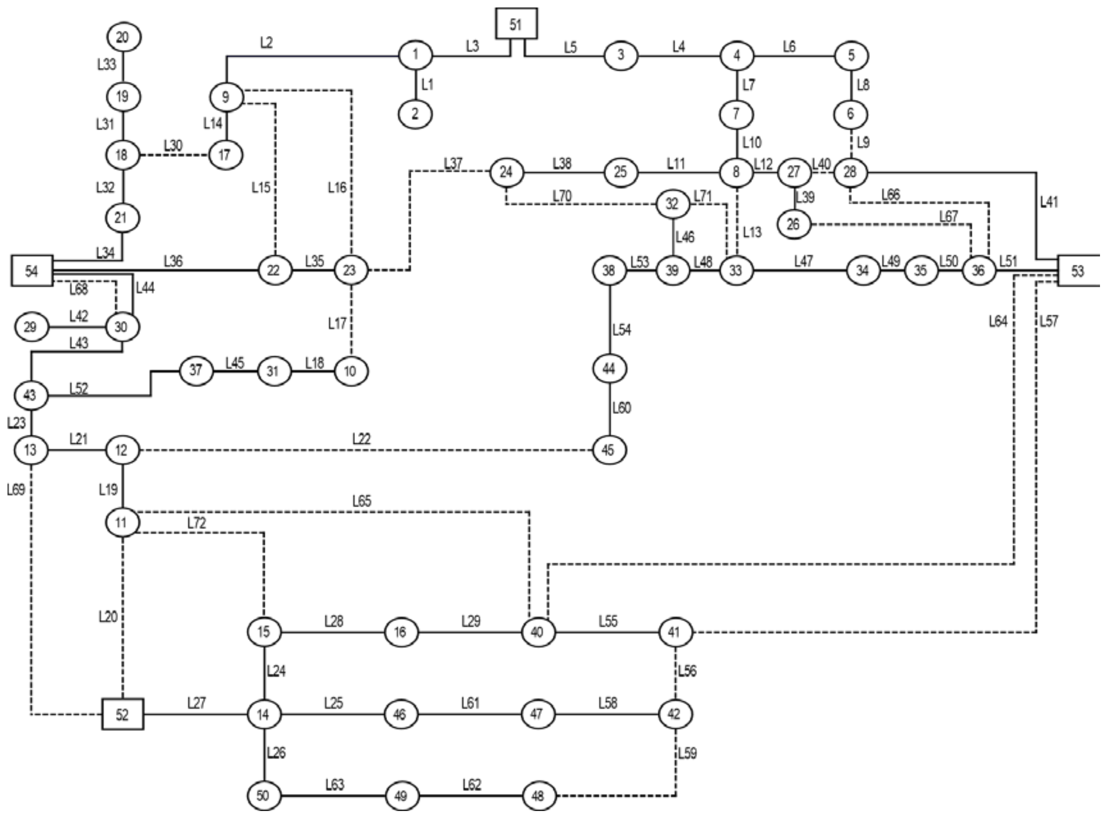
Level of Risk Aversion considered in the expansion and planning exercise (→ λ)

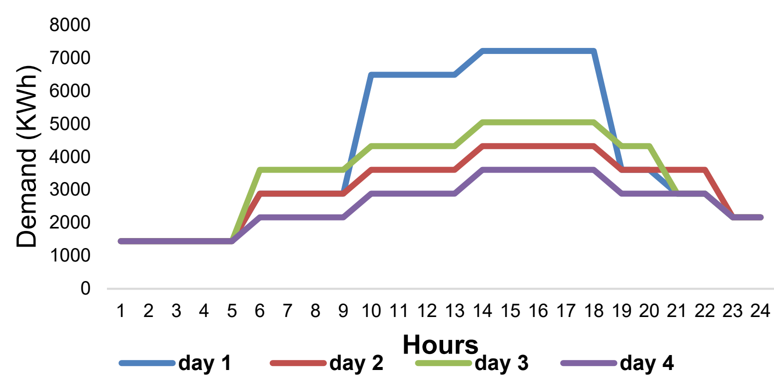
nodal balance constraints
power flow constraints
substations constraints
time coupling constraints

} For each hour “t” of a typical day “d”

Case Study

- Distribution Feeder
  - 13.5 kV
  - 54 Nodes
  - 7 MW Peak
  - 50 Existing Lines
- Planning
  - 22 New connection plans
  - 4 Typical Days
  - 1263 scenarios of routine failures, considering rate of failures of 1 per 2.5 years
  - 100 scenarios of HILP events related failures (simultaneous line outages), considering a rate of failures of 1 per 250 years.





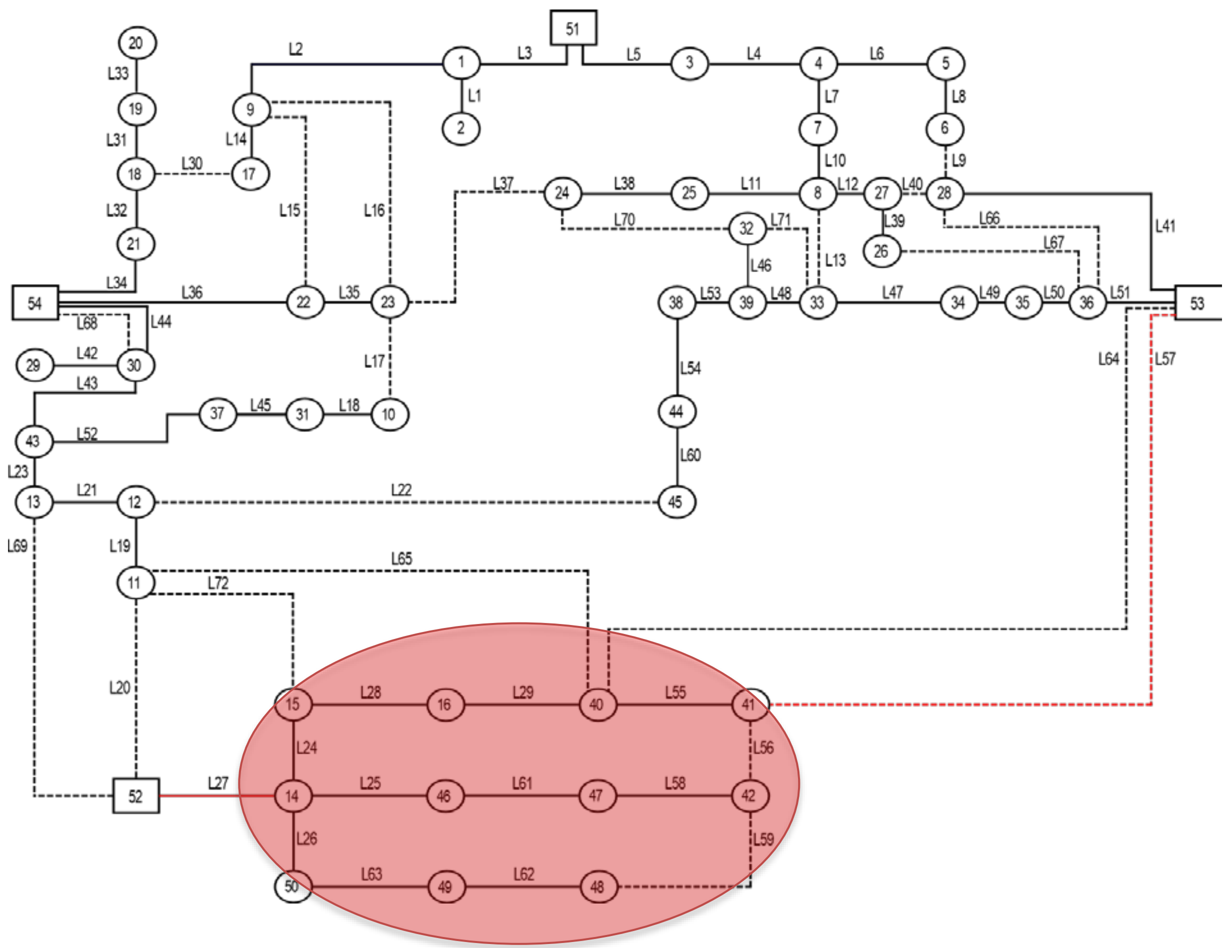
Example of a HILP Event Outage

- Event description

A severe storm can irreparably damage the overhead lines connecting the south part of the feeder once every 250 years.

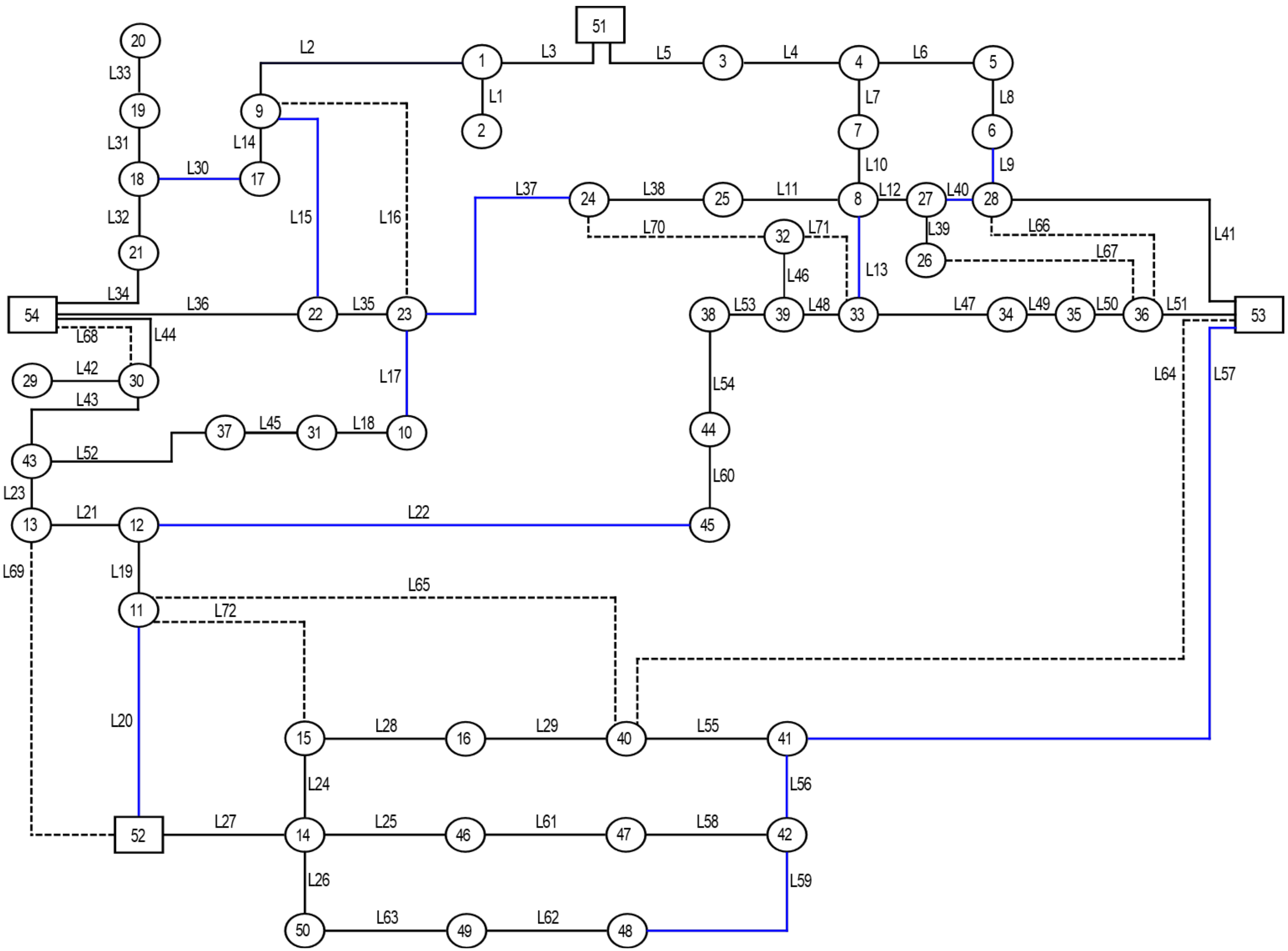
It may take weeks to restore service.

That implies that 20.86% of the demand is isolated for longer periods.



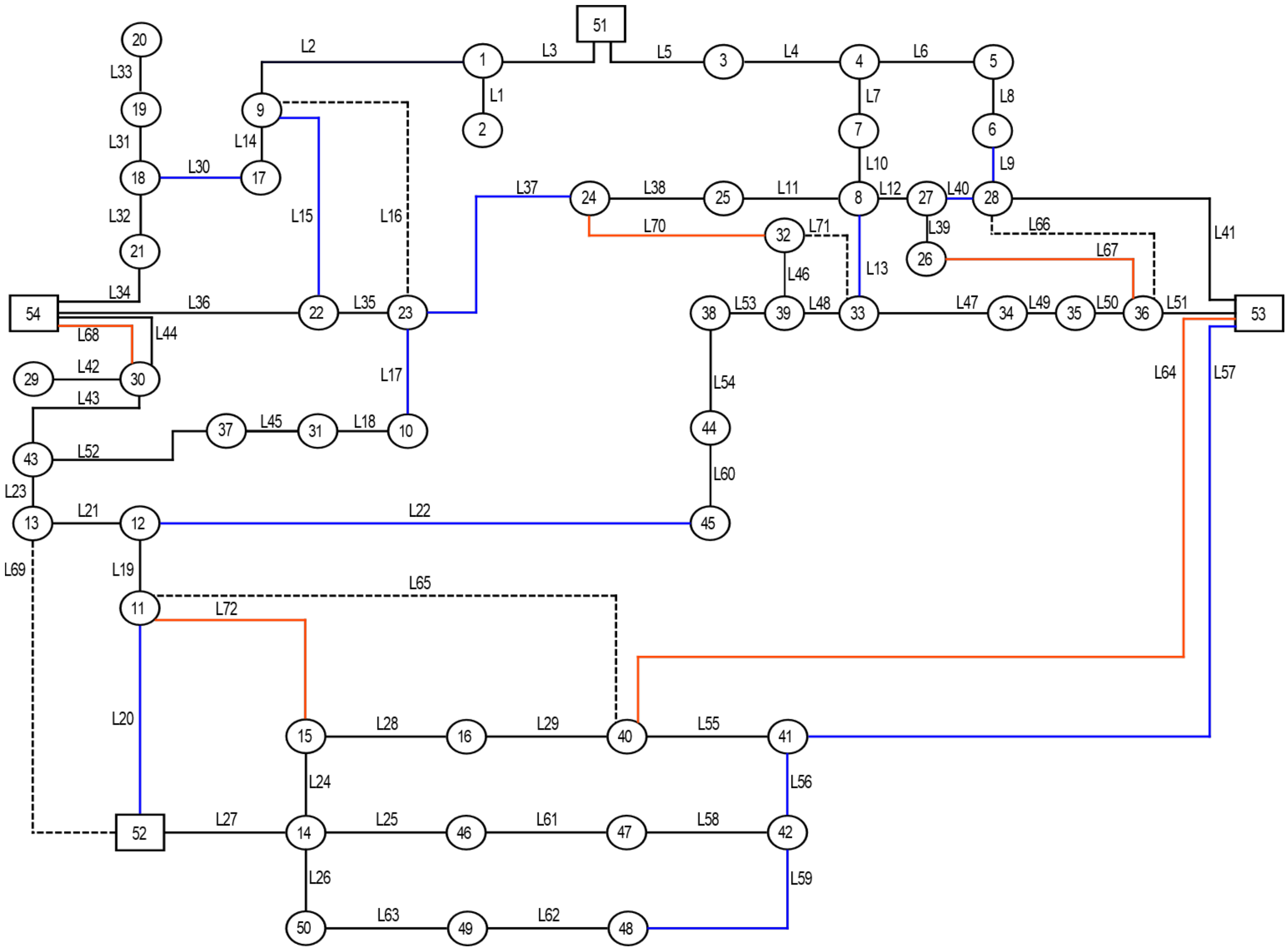
Results: without Resilience Criterion

- Considering Risk Aversion Parameter = 0 (i.e. just reliability)



Results: with Resilience Criterion

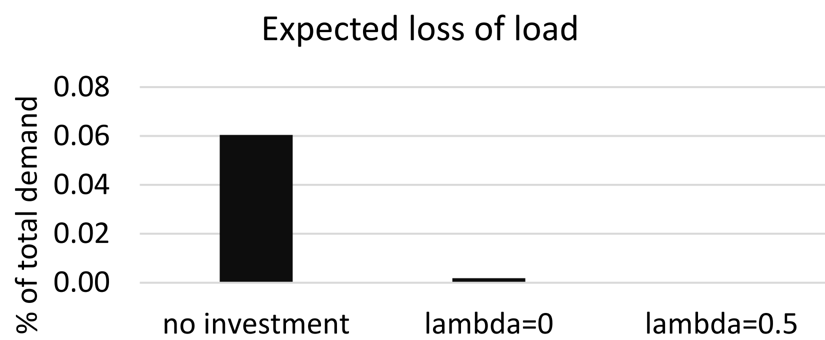
- Increasing Risk Aversion Parameter = 0.5

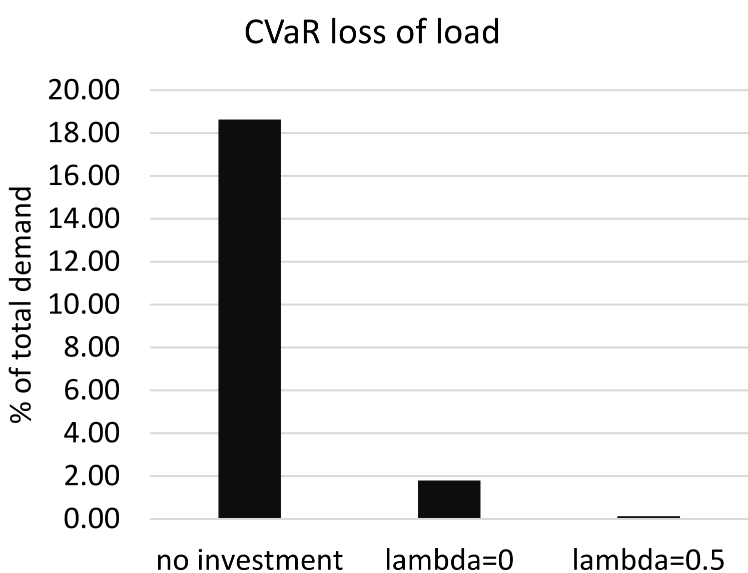


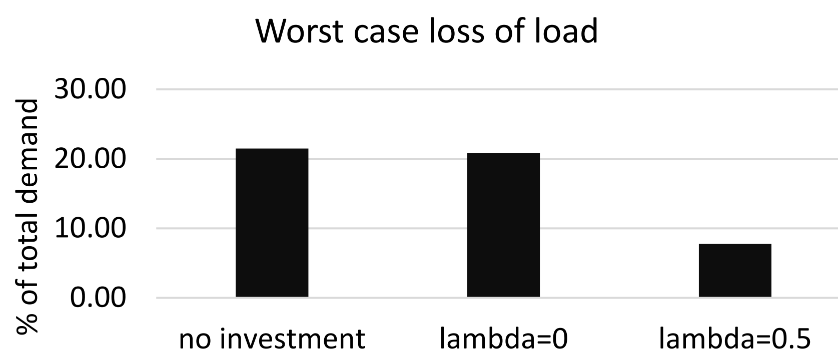
Results

- Costs and Loss of Load for each risk aversion policy

	Risk Aversion $\boldsymbol{\lambda = 0}$	**Risk Aversion** $\boldsymbol{\lambda = 0.5}$
investment (k$)	230	324





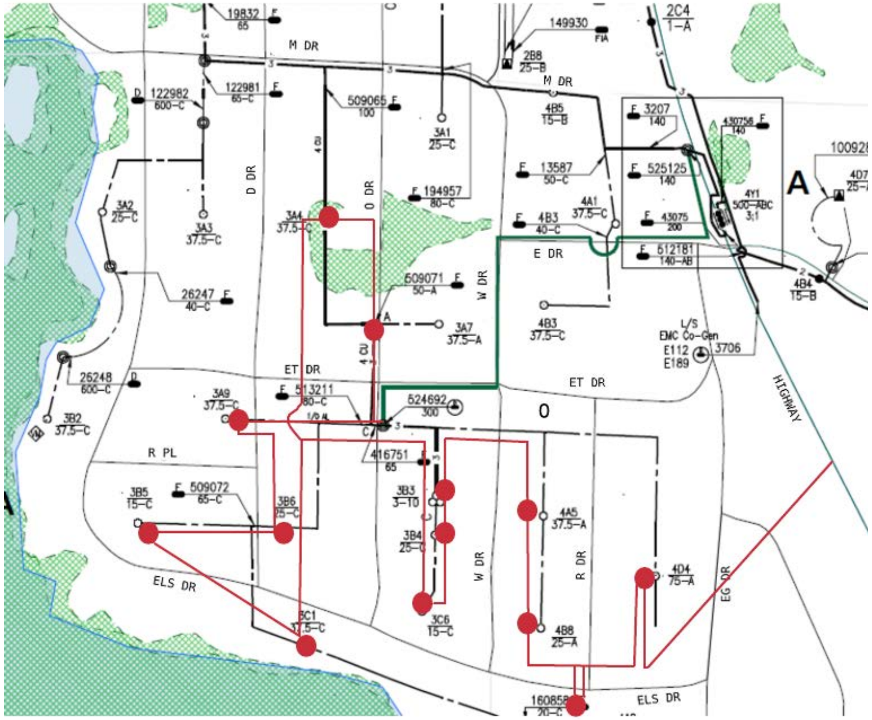


Progress and Results

- Summary:
  - A full stochastic expansion and planning optimization model for electric utilities was developed. This model considers distribution network infrastructural upgrades, such as power line hardening, circuit reinforcement and new loops as well new substations.
  - Reliability network constraints were imposed in a form of expected loss of load per node. These constraints were added to the model above.
  - Resilience network constraints were imposed in a form of CVaR of the loss of load in the different nodes of the systems. This was integrated with the stochastic optimization in a form of “cost vs risk” model, including an explicit parameter that describes the risk aversion policy of the utility when making such investments.
  - The developments mentioned above were implemented in Julia and a Nested Benders Decomposition was used to improve the computational challenges of the full stochastic optimization.
  - Application to a realistic case study involving a distribution network 54 nodes. 22 new projects under 1263 routine failure scenarios and 100 HILP events.

Tech Transfer Activities

- Proof of concept in partnership with ComEd
  - REPAIR will be used to validate existing grid infrastructure upgrades that were done as part of the utility Distribution Reliability Program
  - This ex-post analysis of the investments will allow to compare REPAIR results with a real distribution grid planning process, exploring alternative solutions, and understanding the value of the model for utilities



FY 21: REPAIR Phase II

- Scope of Work:
  - **Include DG and Storage Technologies:** extend the REPAIR model to include DER investments, such as storage and distributed generation technologies. This implies modeling the storage and DG dispatch in response to outage events and capture the value of these resources in the context of reliability and resilience planning.
  - **Include Reliability Distribution Automation:** adding the possibility of investment in distribution automation equipment as part of the grid infrastructure upgrade. This entails modeling operational decisions/actions to mitigate duration and severity of the outages, such as automatic switching and topology reconfiguration during outage events.
  - **Addressing dimensionality of the model:** develop innovative approximations of the intra-day operations of DER and DA that reduce the time component of the model. Explore machine learning based techniques to reduce the spatial dimensionality of the model (for example using inference for network motifs and persistence homology).
  - **Phase II Demonstration with ComEd:** using 2 additional feeders from ComEd's Reliability Program to additional
- Budget:
  - $400k (+$400k from AGM)