Sandia National Laboratories

SAND2019-12954C

Sandia National Laboratories Advanced Grid Modeling Research

PRESENTED BY

Ray Byrne, Ph.D.

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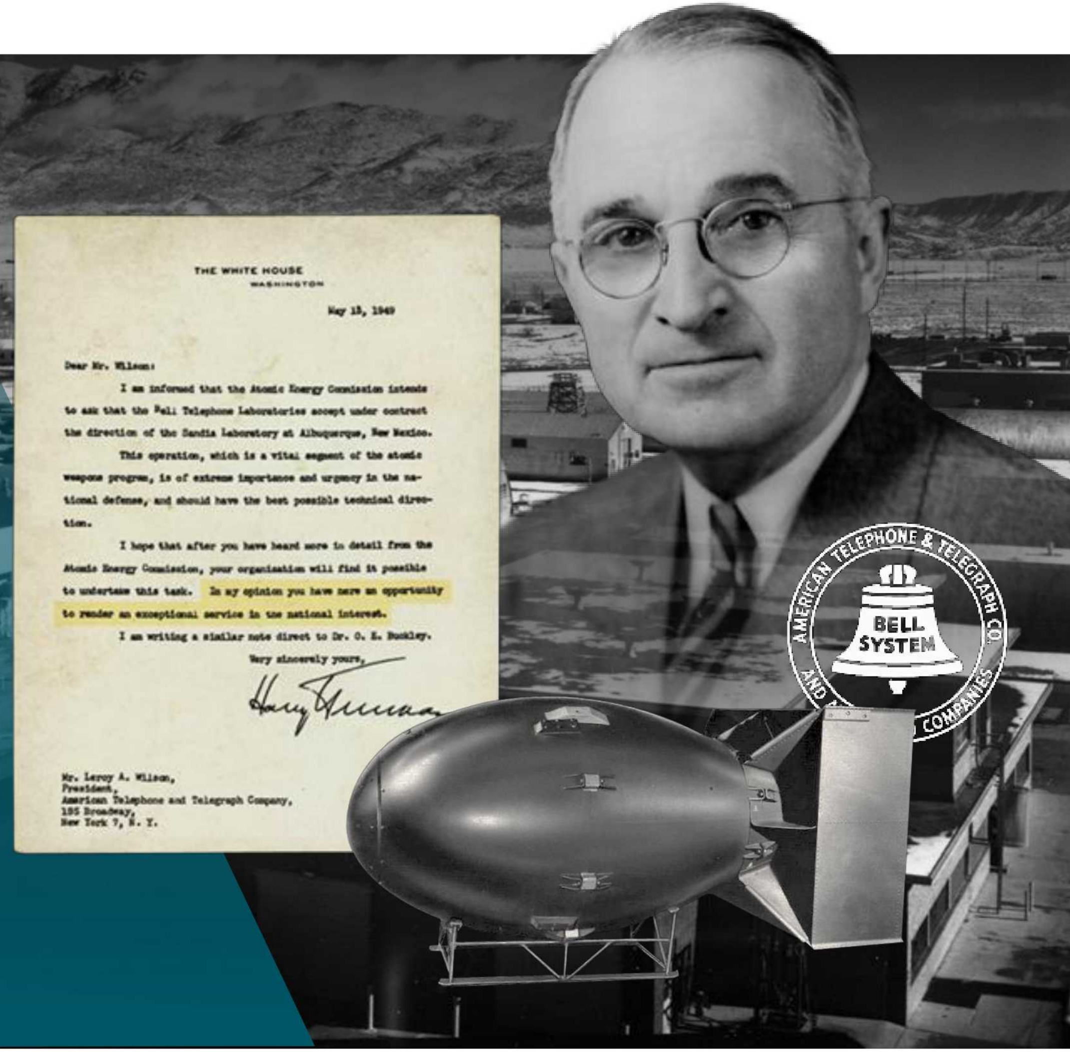
Outline

- Sandia Overview
- Examples of Grid Research at Sandia
- Student Intern Opportunities

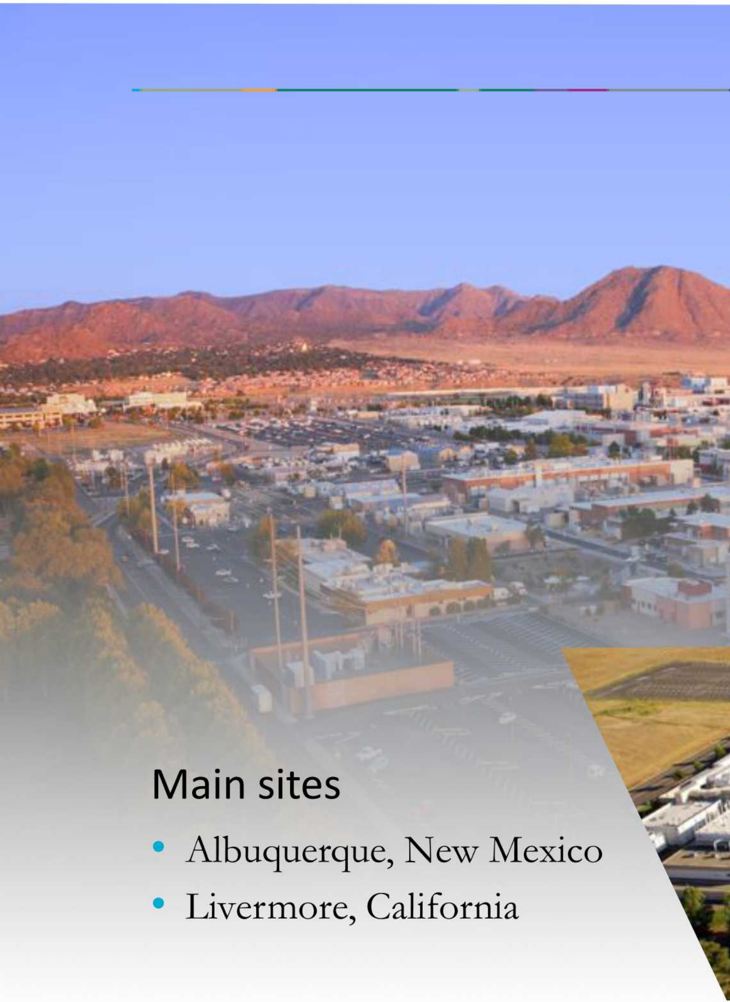
Sandia's History is Traced to the Manhattan Project

…In my opinion you have here an opportunity to render an exceptional service in the national interest.

- July 1945
  Los Alamos creates Z Division
- Nonnuclear component engineering
- November 1, 1949
  Sandia Laboratory established
- AT&T: 1949–1993
- Martin Marietta: 1993–1995
- Lockheed Martin: 1995–2017
- Honeywell: 2017–present



Sandia has Facilities Across the Nation



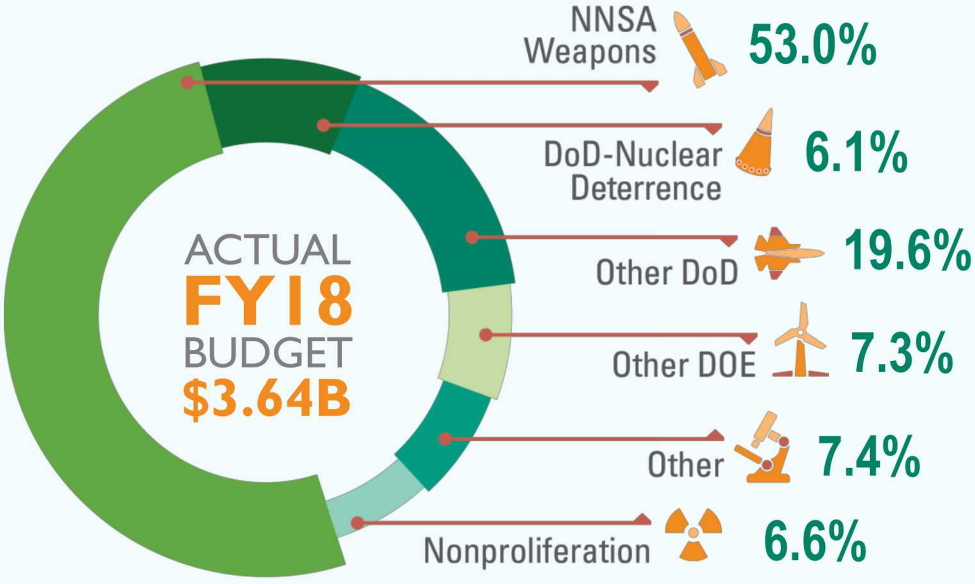
Activity locations

- Kauai, Hawaii
- Waste Isolation Pilot Plant, Carlsbad, New Mexico
- Pantex Plant, Amarillo, Texas
- Tonopah, Nevada

Main sites

- Albuquerque, New Mexico
- Livermore, California

Sandia's Budget Covers a Broad Range of Work



DoD

Air Force | Army | Navy
Defense Threat Reduction Agency
Ballistic Missile Defense Organization
Office of the Secretary of Defense
Defense Advanced Research Projects Agency
Intelligence Community

OTHER DOE

Science
Energy Efficiency and Renewable Energy
Nuclear Energy
Environmental Management
Electricity Delivery and Energy Reliability
Other DOE

OTHER

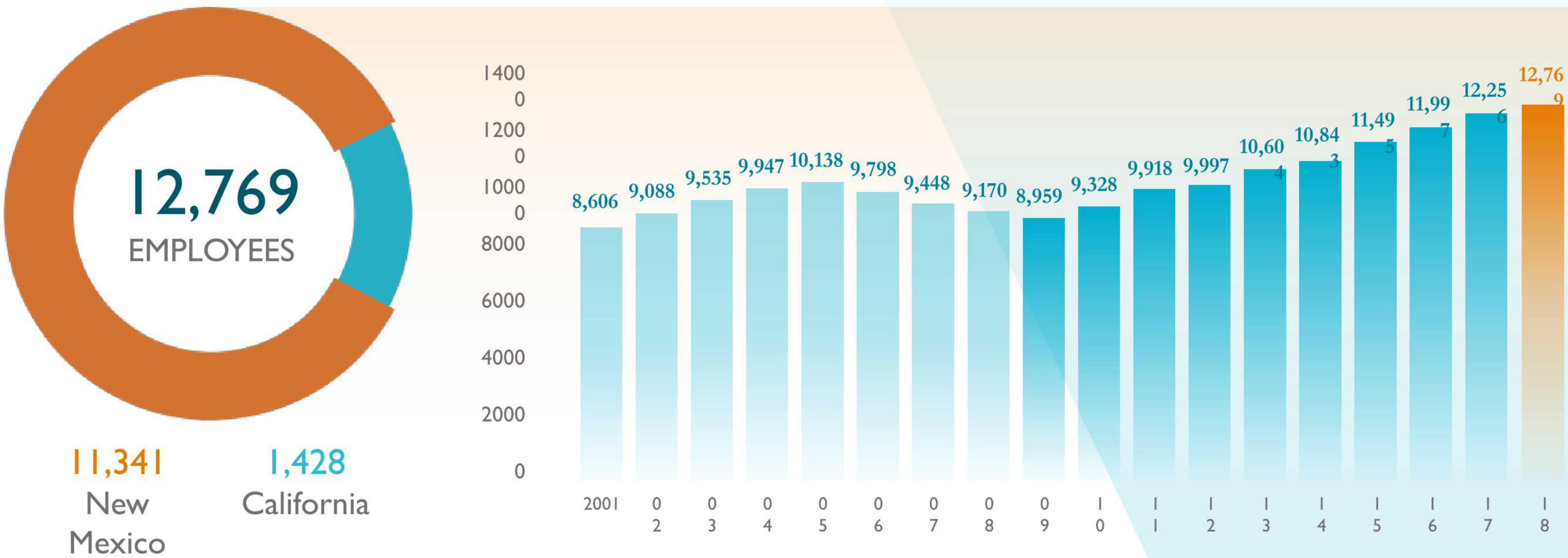
Department of Homeland Security
Other federal agencies | Nonfederal entities
CRADAs, licenses, royalties | Inter-entity work

NONPROLIFERATION

NNSA/NA20 | State Department

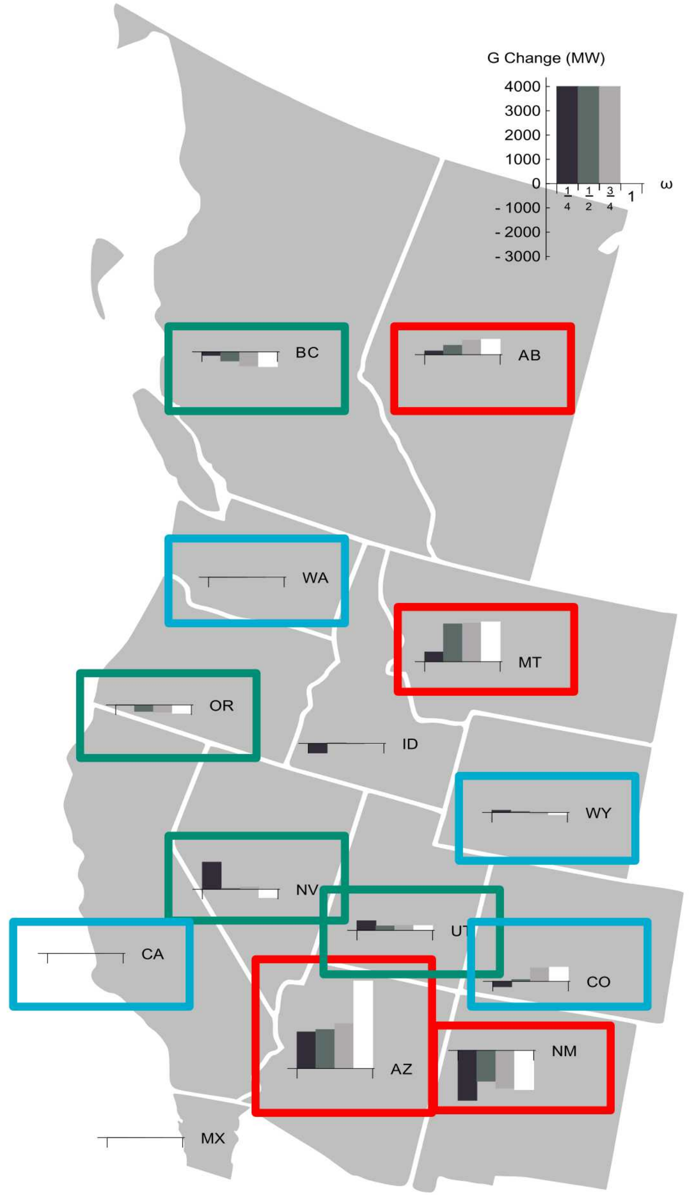
Sandia's Workforce is Growing

Staff has grown by over 3,800 since 2009 to meet all mission needs



Stochastic Transmission and Generation Planning

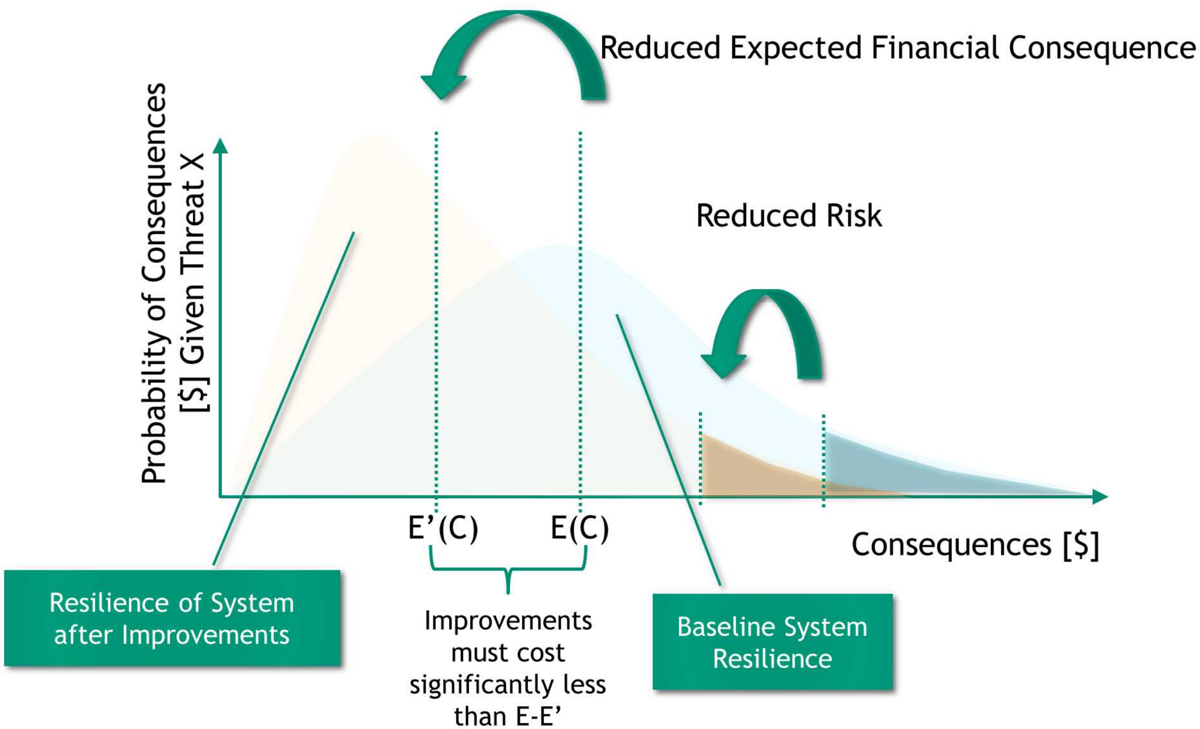
- Developed algorithms and tools for stochastic transmission and generation planning
- Minimize weighted sum of expected cost and CVaR
- Case study: WECC 240 bus system (2013 planning study)
- Changes in generation investments per state w.r.t. risk-neutral case
- Risk aversion leads to:
    - Increases in generation investments in AB, MT, AZ, and CO
    - Reductions in generation investments in BC, OR, NV, and UT
    - No changes in CA, WA, and WY
- => Ambiguous effect



Modeling and Optimization of Electric Grid Resilience

Project Objective: To develop scalable optimization models for power grid resiliency at the transmission level, with high-fidelity models, that is ultimately deployable for experimental purposes

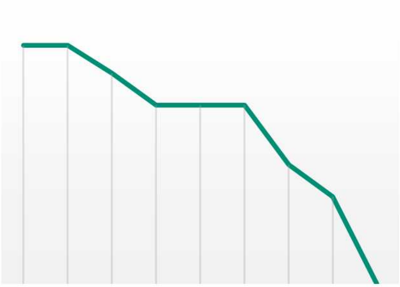
- Sandia developed a framework for rigorous quantification of energy system resilience
- This framework enables decision making to obtain demonstrable resilience improvements



- Resulting resilience metrics are probabilistic
- The framework is flexible:
  - Can handle different types of threats
  - Provides information for different types of decision makers

Modeling and Optimization of Electric Grid Resilience

Two-Stage Stochastic Resiliency Model



Decide grid components *to harden*

- Can harden lines, generators, and buses within a budget
- Each component has an investment cost

Hurricane scenario

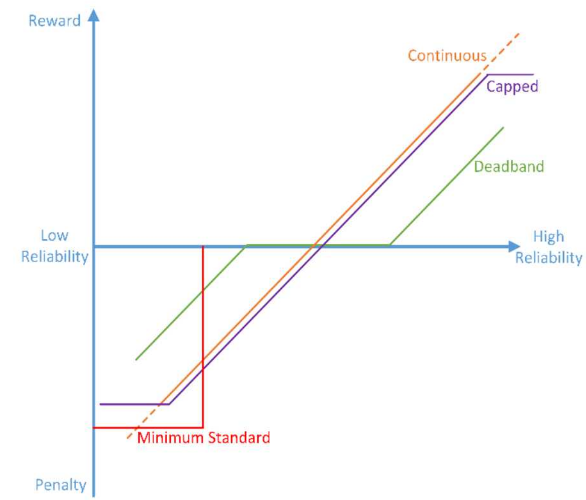
- Unless they are hardened, some components are rendered inoperable for some duration

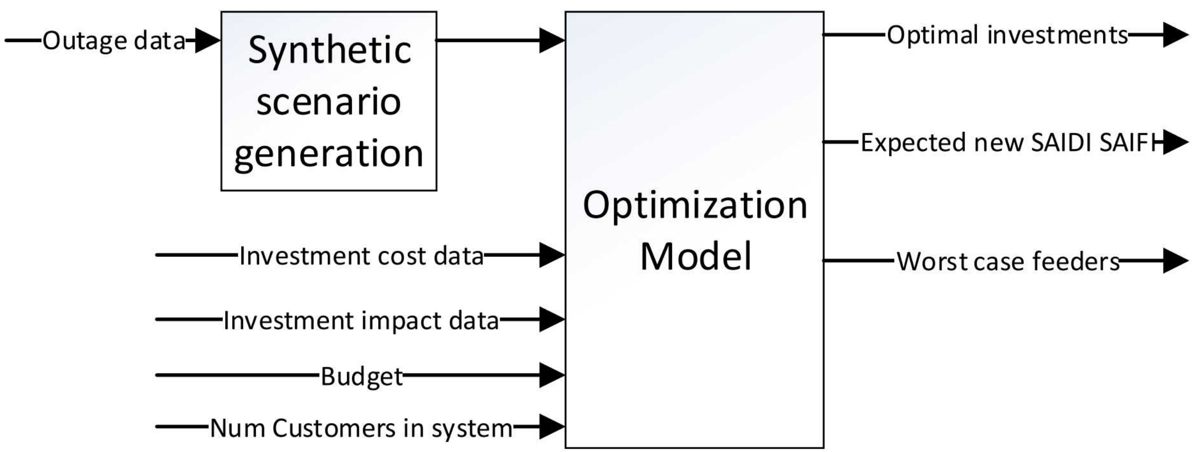
Recovery plan

- Given the state of the network after the hurricane, decide grid operations across time horizon, minimizing load shed
- Unit commitment and transmission switching

Co-Optimization of Resilience and Reliability

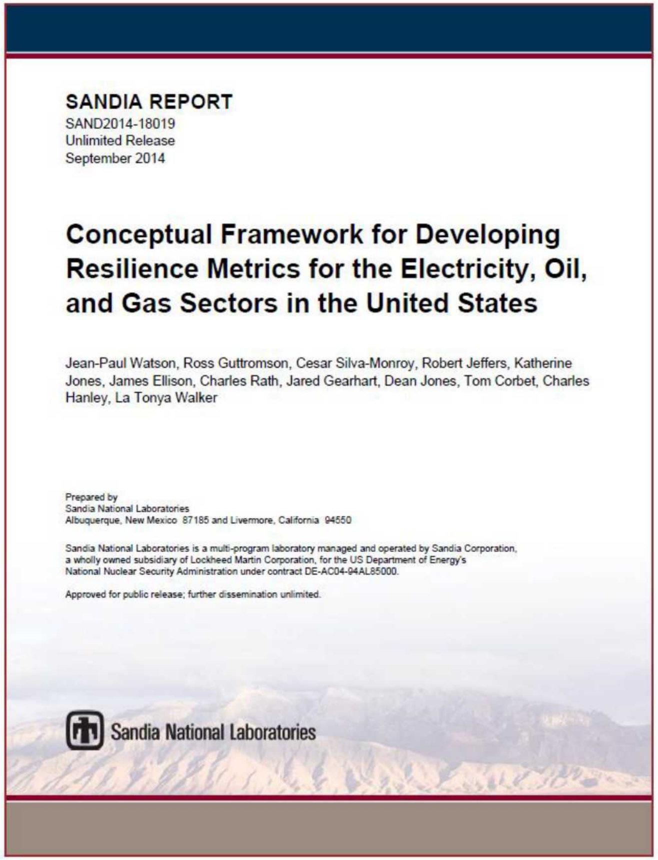
- Utilities are incentivized to be reliable but not resilient
- Utilities are often incentivized to be more reliable (improve their SAIDI and SAIFI metrics)
- Some utilities have performance based regulation (PBR)
- Large scale events (severe winter storms, hurricanes, etc.) are removed from the SAIDI and SAIFI metrics
- Less incentive to invest in resiliency
- Sandia is developing optimization techniques to Co-optimize resilience and reliability (current AGM project)





Resilience Metrics

- Resilience metrics and optimizing for resilience/reliability are closely related
- Sandia has extensive experience developing resilience metrics
- Sandia's JP Watson co-leads the NAERM Threats, Economics and Metrics thrust


SANDIA REPORT
SAND2014-18019
Unlimited Release
September 2014

Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States

Jean-Paul Watson, Ross Guttromson, Cesar Silva-Monroy, Robert Jeffers, Katherine Jones, James Ellison, Charles Rath, Jared Gearhart, Dean Jones, Tom Corbet, Charles Hanley, La Tonya Walker

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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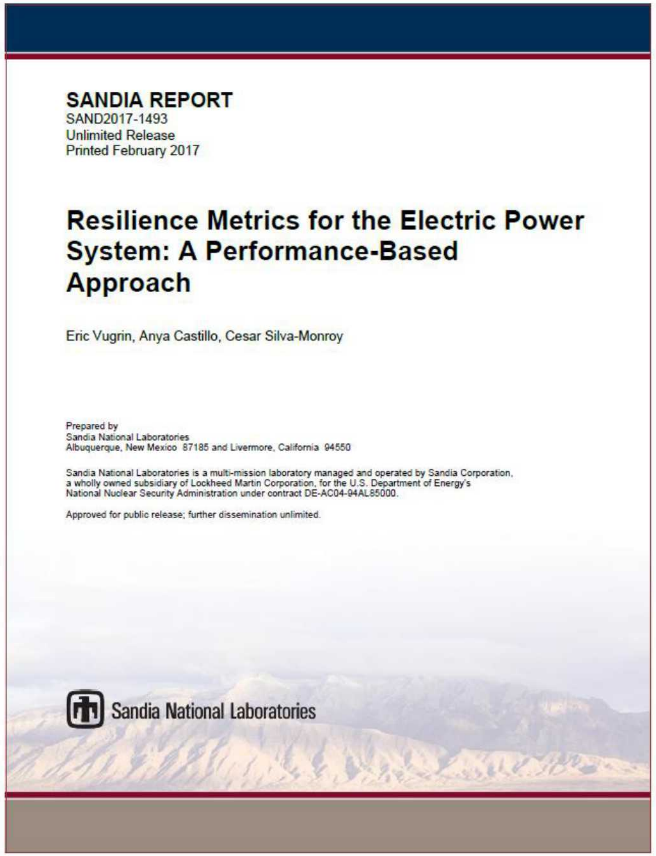
SANDIA REPORT
SAND2017-1493
Unlimited Release
Printed February 2017

Resilience Metrics for the Electric Power System: A Performance-Based Approach

Eric Vugrin, Anya Castillo, Cesar Silva-Monroy

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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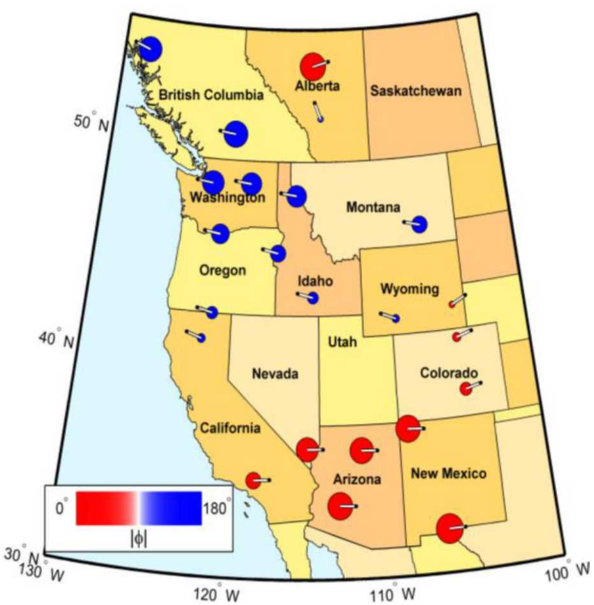
Sandia National Laboratories

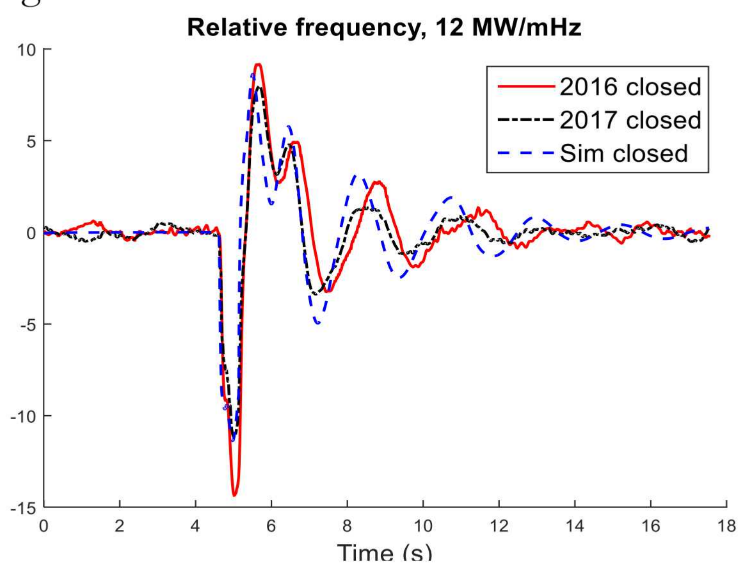
Small Signal Stability

Sandia has extensive experience with small signal stability

- DOE/BPA/Sandia/Montana Tech wide area damping control project
- Power system dynamic modeling and simulation (e.g., PST, PSLF, PSSE)
- Small signal stability analysis – Prony, ERA, etc.
- Controller design – Optimal Fixed Structure Control (OFSC), decentralized control, network-enabled feedback control, design for various actuators
- Impact of high renewable penetrations
- Mode visualization
- Supervisory controller design

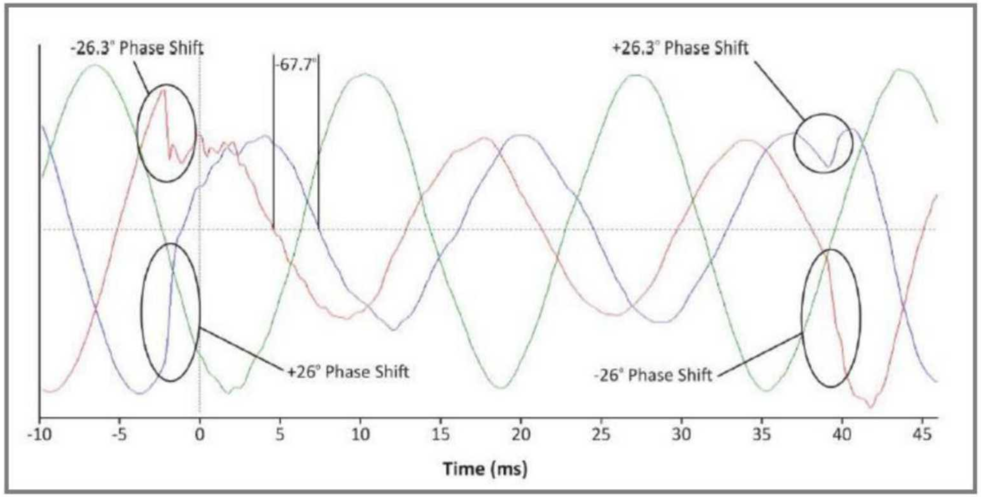
North-South Mode





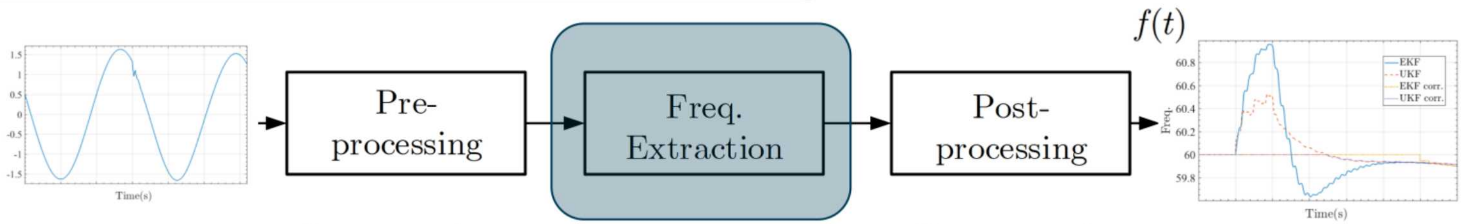
Frequency Estimation

Project goal: develop frequency estimation algorithms that are robust to waveform distortions to enable synthetic inertia



- **Key research question:** For a corrupted (distorted, noisy) waveform, what is frequency?

Figure from *1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report Southern California 8/16/2016 Event* NERC Report



Input:
- Single phase
- Three phase
- Multisignal

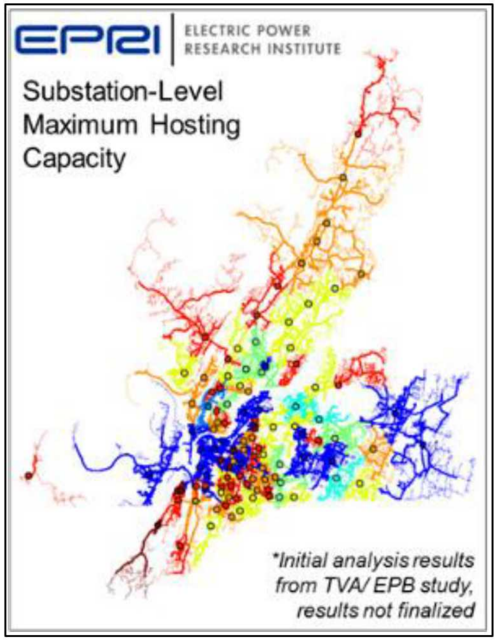
Preprocessing (optional)
Filtering to reduce noise and distortion

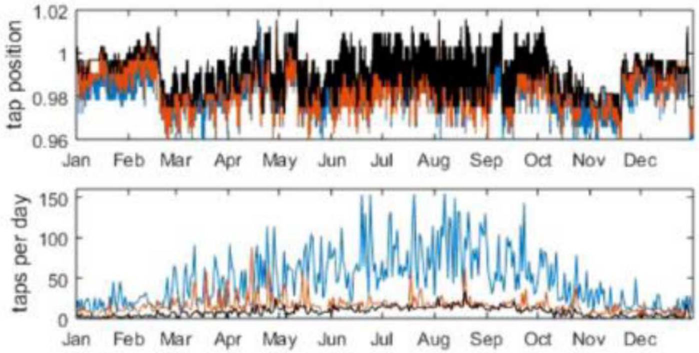
Estimation algorithms
- Discrete Fourier transform (DFT) based
- Kalman Filter (KF) based
- Phase-locked loop (PLL) based
- Adaptive Notch Filter (ANF)
- Least squares based

Postprocessing (optional)
Filtering to reduce noise
Correction of faulty estimates

Machine Learning to Improve Distribution System Models

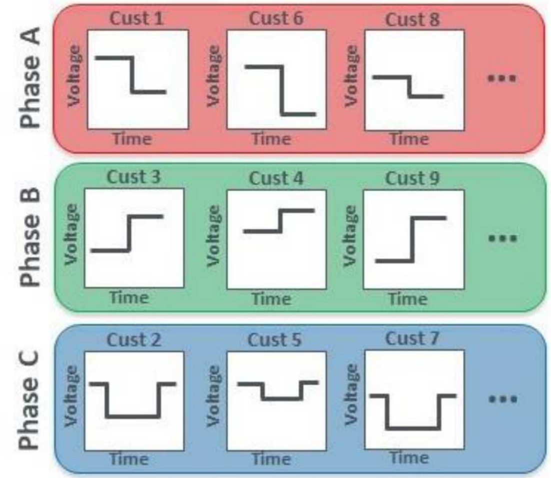
- The distribution system has been built over many decades, historically recorded with paper schematics for installations, upgrades, and maintenance.
- Distribution System Models
  - Are based on manual data entry that is prone to error and often out of date
  - Contain additional complexity because they are multi-phase unbalanced with single-phase customers. Cannot use symmetrical component single-line models from transmission system modeling
- Sources of Error
  - Unlogged or erroneous maintenance reports
  - Information not initially recorded in the model
- Recent additions of Advanced Metering Infrastructure (AMI), or smart meters, provide measurements of each customer's power consumption, and possibly other quantities, such as voltage, that provide new insights and levels of accuracy in distribution system modeling
- Distribution modeling errors in aggregate impact the fidelity of transmission models



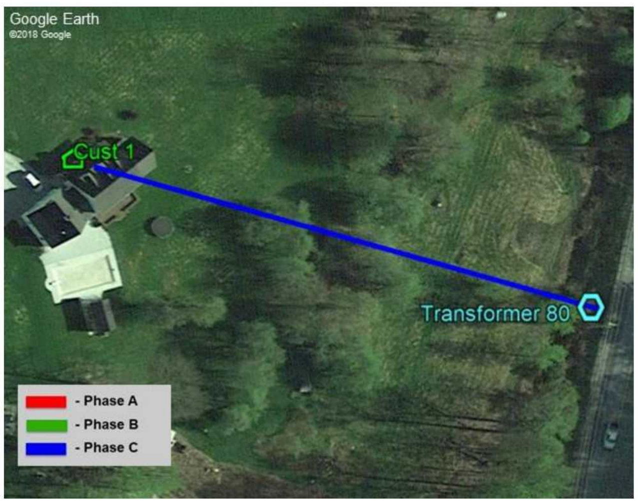


Phase Identification Results

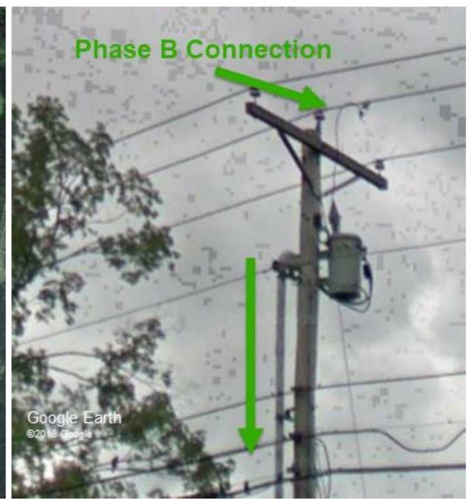
- Algorithm predicts the phase for each customer (generally confirming the utility model)
- Example of the algorithm detecting an error in the model and predicting the correct phase (as verified in StreetView



Concept

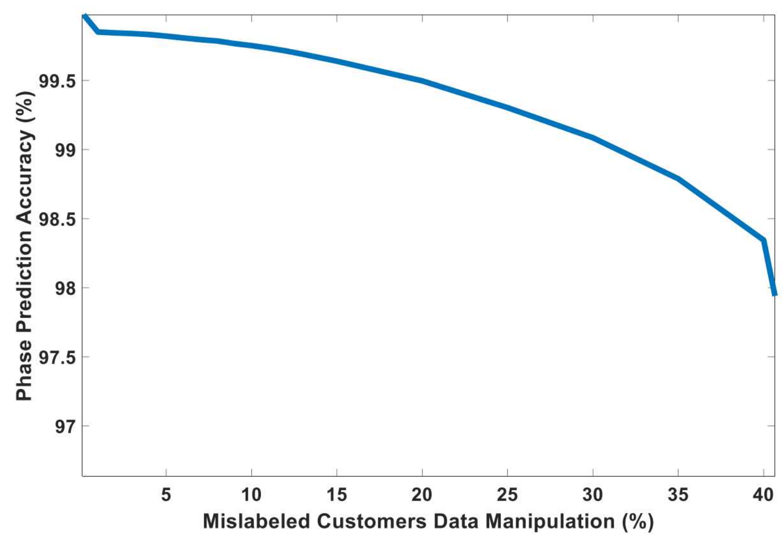


Original Utility Model Labeling



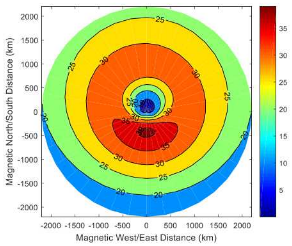
Google Street View Showing a Phase B Connection

Using the synthetic data with known number of model errors, the algorithm accurately predicts the phase with >98% accuracy

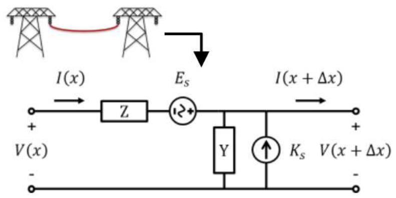


EMP Resilient Grid LDRD

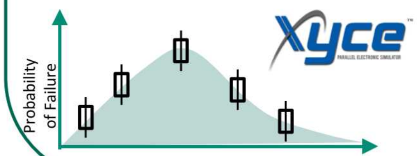
Thrust 1 Vulnerability Assessment



Environments

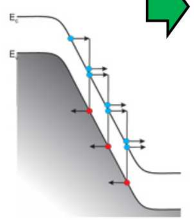


Coupling



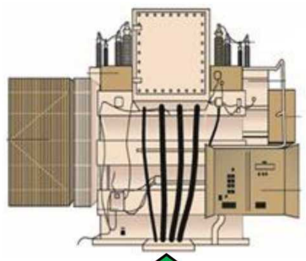
Failure Analysis

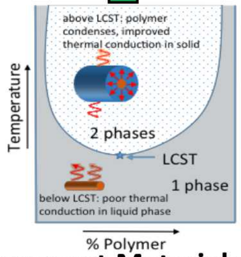
Thrust 2 Material & Device Innovation



Avalanche Breakdown in a Wide Band-Gap diode

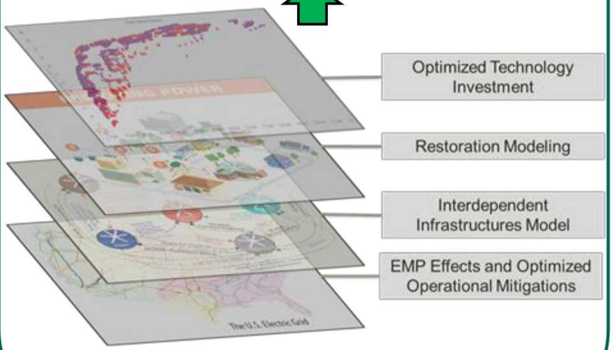
EMP hardened assets





Design New Component Materials to Withstand EMP Effects

Thrust 3 Optimal Resilience Strategies



Modular Multi-Layered Modeling Approach

R&D

- Large scale coupling modeling with significant number of unknowns
- Component response and failure estimation to EMP waveforms

R&D

- Develop Wide Band-Gap EMP arrestor
- LCST Polymers for thermal management during E3/GMD

R&D

- Baseline assessment of EMP Effects w/ Large Scale Stochastic, AC Dynamic Optimization
- Risk mitigation by Tech Deployment, Operational Mitigation & Optimal Restoration

Georgia Tech | Research at Purdue | EPRI | Los Alamos National Laboratory EST. 1943

SECURE (**S**cience and **E**ngineering of **C**ybersecurity by **U**ncertainty quantification and **R**igorous **E**xperimentation) LDRD

Sandia's SECURE LDRD is developing algorithms and tools that enable a scientific community of practice to rigorously quantify security

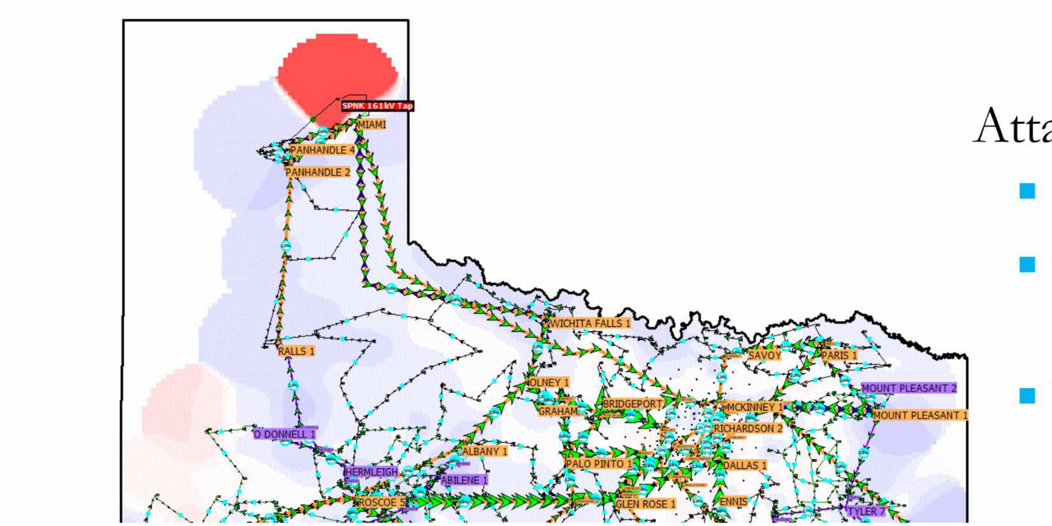
Cyber experimentation is essential for securing cyber systems

- collective behavior is hard to predict
- experimenting on a live system is not an option

Computational experimentation is a powerful tool

- But lack of rigor limits adoption for high-consequence decisions

SECURE integrates cyber Emulytics, Uncertainty Quantification and Optimization methods to quantify and mitigate cyber risks



Attack Budget of '1':

- RTU-4 Compromised
- Total Panhandle Load Shed: **237.97 MW (75%)**
- Voltage Security Violations

*Derived from synthetic data with no relation to actual grid: https://electricgrids.engr.tamu.edu/electric-grid-test-cases/activsg2000/

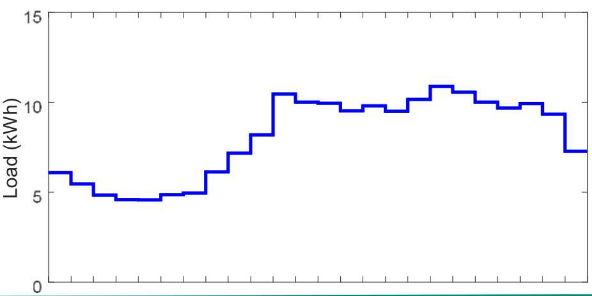
Packetized Delivery of Energy LDRD

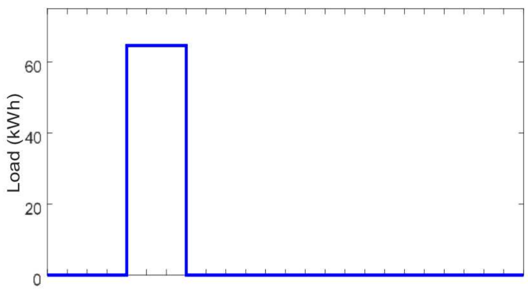
Fixed-schedule delivery scheme

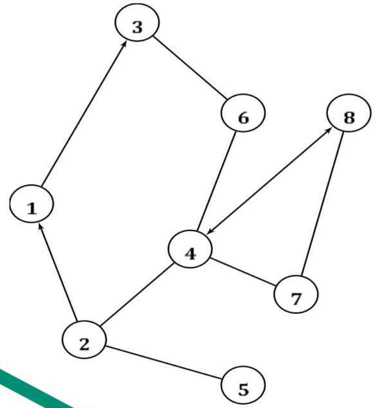
- The grid operator will specify the size and the delivery time of each packet on daily basis.
- This decision is based on an optimization to minimize a cost function under the system's constraints.

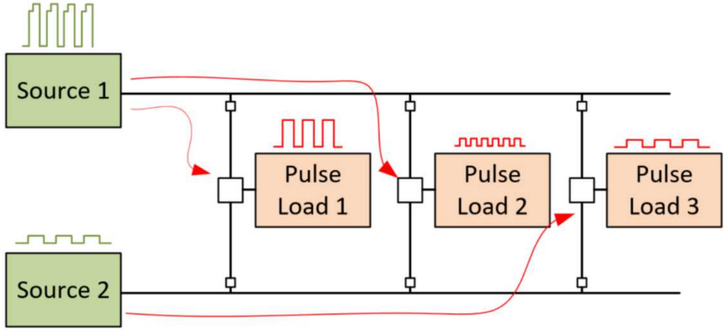
Flexible-time delivery scheme

- The customers can request an immediate delivery of energy packets.
- This on-demand delivery of energy can be implemented using explicit routing schemes developed for internet traffic engineering.









Research Objectives

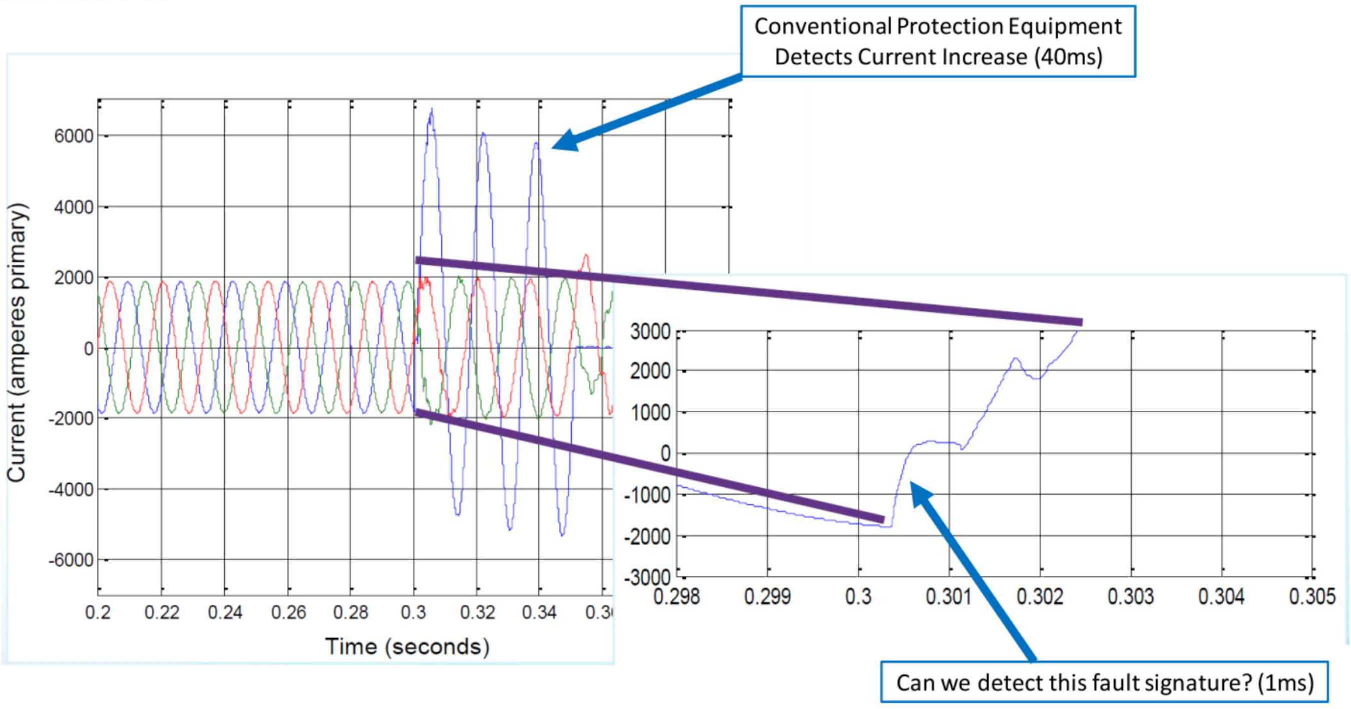
- Determine optimal energy packet protocols.
- Converter controls & H/W protocol implement

- Advantage:
  - Increase power density
  - Prioritization of load
- Goal: instead of constrained AC or DC voltage, use an asynchronous broadband power and communication system.

Signal-Based Fast Tripping Protection Schemes for Electric Power System Resilience LDRD

Goals: improve grid resilience by developing new signal-based protection schemes that quickly detect the fault locally within 0.02 seconds without communication. Plan to investigate signal-based protection methods such as wavelet transformation, power line carrier, spectrum impedance testing, and travelling wave.

Hypothesis: high-frequency measurement can be combined with signal-based methods to quickly detect the fault locally within 0.02 seconds without communication.

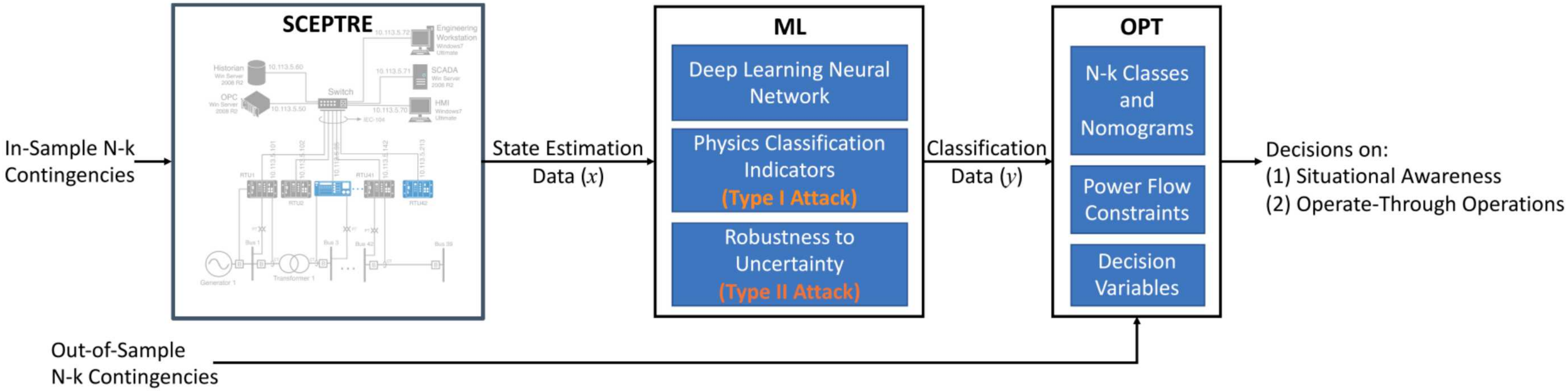


REDLY (Resilience Enhancements Through Deep Learning Yields) LDRD

Goals: To develop scalable methods for system operators to protect the grid against physical damage and interrupted service caused by cyber attacks through integration of physics-constrained, robust machine learning (ML) and optimization (OPT) methods to deliver on both (1) situational awareness and (2) operate-through capabilities specifically for N-k contingencies.

Hypothesis: by integrating ML and OPT, the methods require less data for training, and are more scalable and tractable for solving than general purpose ML algorithms (like AlphaGo and AlphaZero).

<u>Experimental Design</u>



Student Intern Opportunities

Sandia has two types of student intern opportunities

- Year-round student intern
- Summer student intern

How to search for grid-related student intern positions:

- Navigate to: http://www.sandia.gov/careers/
- Click on "View all jobs"
- Search for the department of interest:
  - 08811 Energy Storage Technologies and Systems
  - 08812 Renewable and Distributed Systems Integration
  - 08813 Electric Power Systems Research
- Screen by job type (e.g., summer student intern)

Areas of expertise that we are looking for

- Optimization (production cost modeling, transmission planning, resilience modeling, stochastic optimization)
- Control theory (transient stability, optimal control, distributed control)
- Electric Power system protection
- Distribution system modeling, microgrid design
- Machine learning applied to power systems (especially with respect to protection)
- Working towards a Ph.D. in electrical engineering or related field