U.S. DEPARTMENT OF
ENERGY
Office of Electricity

# Evaluation of Grid Equipment for Improved Resilience

**TRAC Program Review**

*US Department of Energy, Office of Electricity*

**Presented at Oak Ridge National Laboratory**

*Oak Ridge, TN*

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**Dr. Bjorn Vaagensmith, Power Systems Researcher**

*Idaho National Laboratory*

***Bjorn.Vaagensmith@inl.gov***

# Project Overview

- Investigate methodologies and best practices for prioritizing electric power grid equipment improvements
  - Best return on investment for resilience improvements

- Total award: $500k

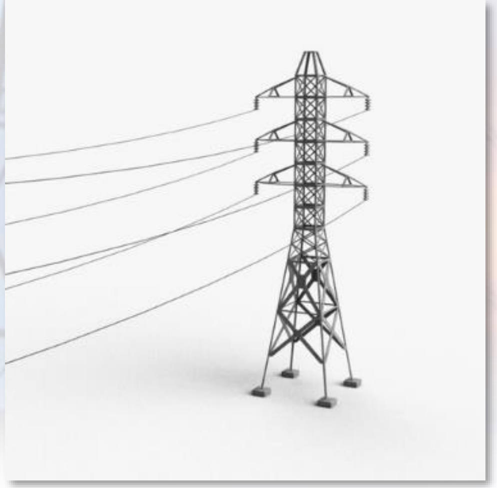
- Period of performance: Sept 15, 2017 – December 31, 2018

- Bjorn Vaagensmith (PI), Jesse Reeves, and Carol Reid (PM)

# Context concerning the problem being addressed

- Power grid operations are critical to modern society
  - Economics
  - Culture
  - Maintain livable conditions

- Understanding the most important power grid components can help researchers and utilities create a more resilient power grid

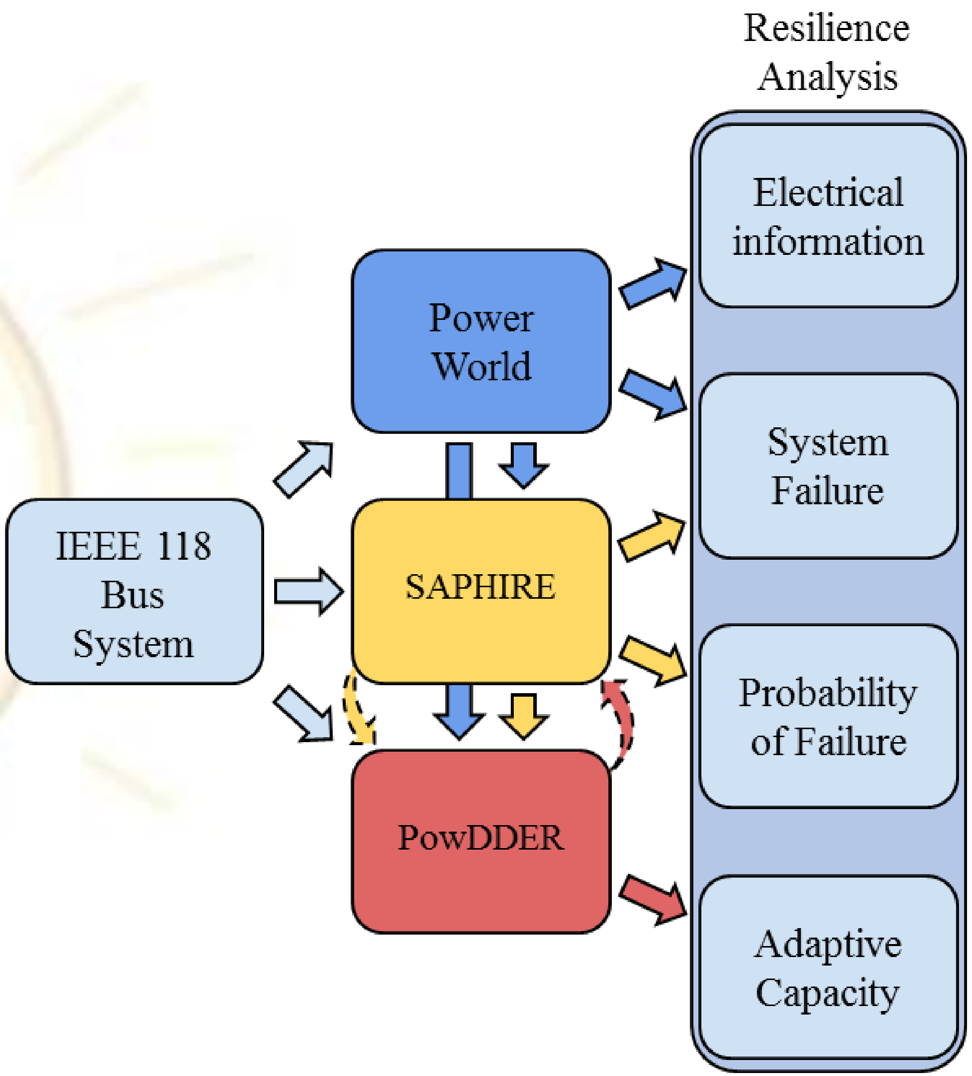


# State of the art approaches for addressing the problem

- Utilities focus on power flow studies to prevent outages and fast response to failed equipment
- Nuclear regulatory commission uses probabilistic risk assessment (PRA)
- PRA used to predict the most likely sequence of events that result in a power outage
- Resilience studies focused on microgrid architecture, control algorithms, and distributed generation

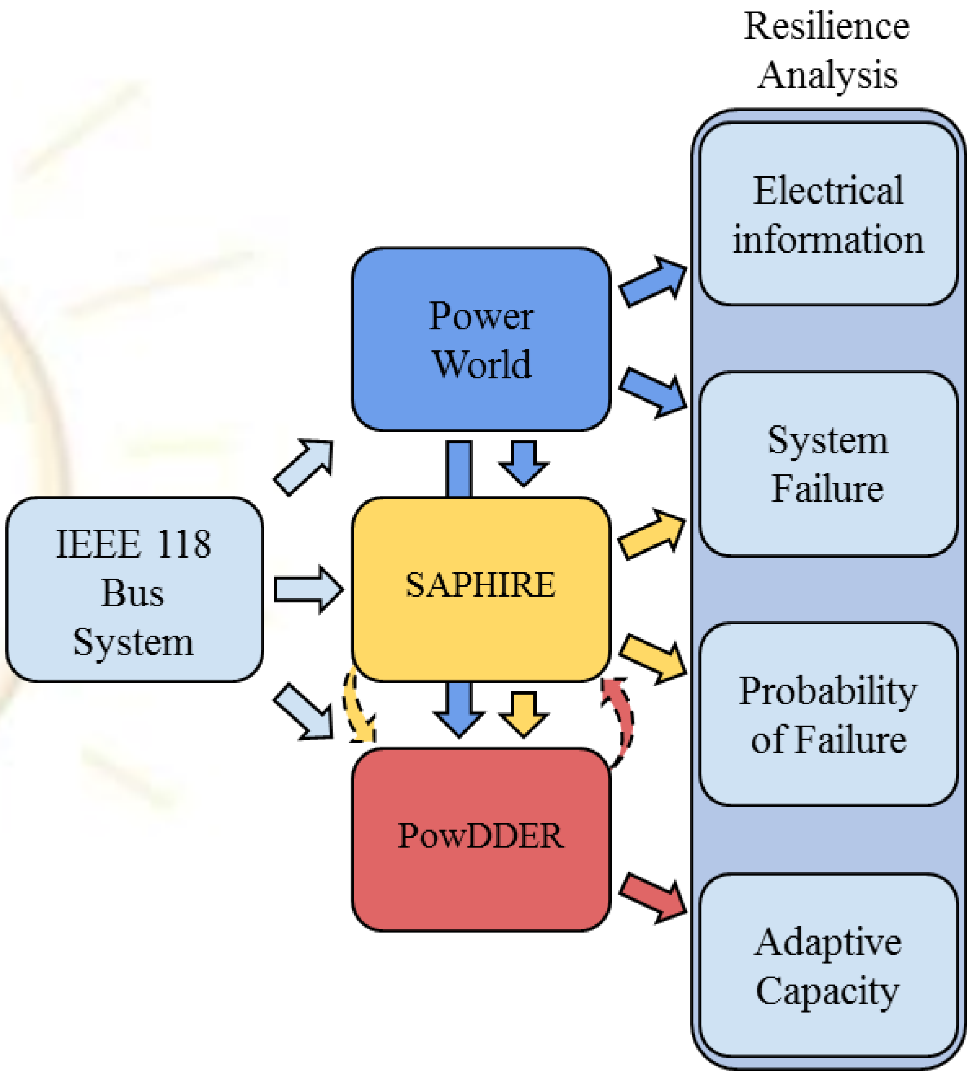
# Uniqueness of the proposed solution

- Combine power flow, PRA and resilience metrics
- Iterative relationship between Power World and SAPHIRE & PowDDER
- Programs modeled outcomes for:
  - Electrical information
  - System Failure
  - Probabilities of Failure
  - Adaptive Capacity (Resilience metric)



# Technical explanation of the proposed approach

- PowerWorld:
  - Contingency analysis → SAPHIRE
  - Power flow and system information → PowDDeR
- SAPHIRE:
  - Likelihood of specific components cause system failure
  - Most likely failure scenarios → PowDDER
- PowDDER:
  - Largest changes in adaptive capacity
  - Potential power pinch points



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# Significance: data mining form OE-417 vs SAPHIRE simulation

**OE-417 data: Significantly contributing component failure associated with high wind**

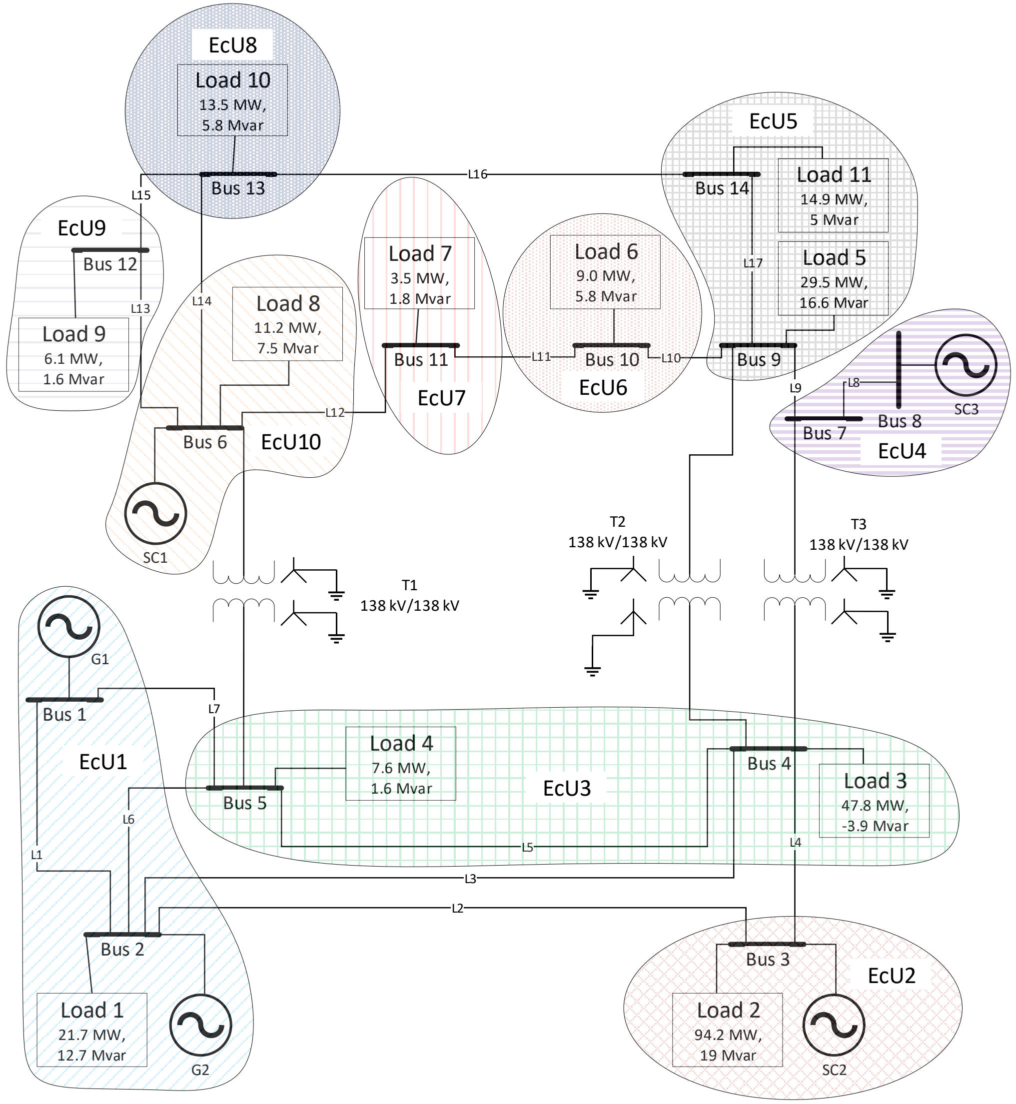
| Component | 2017 | 2016 |
|---|---|---|
| Power Lines | 59 | 29 |
| No Data Found | 3 | 2 |
| Transformer | 1 | 1 |

**SAPHIRE IEEE 14 bus model: Generic component results unavailability/hour (UA/h) that contributed to system wide failure**

| Group (n-1) | Nominal, Single Bkr (UA/h) | Nominal, Bkr & Half (UA/h) | HW, Single Bkr (UA/h) | HW, Bkr & Half (UA/h) |
|---|---|---|---|---|
| Generators | 5.97E-08 | 3.63E-08 | 5.97E-08 | 3.63E-08 |
| Synchronous Condenser | 1.38E-07 | 9.89E-08 | 1.38E-07 | 9.89E-08 |
| Transformer | 1.58E-04 | 5.35E-05 | 3.78E-04 | 3.25E-04 |
| Powerlines | 1.47E-03 | 1.61E-04 | 2.37E-03 | 1.06E-03 |

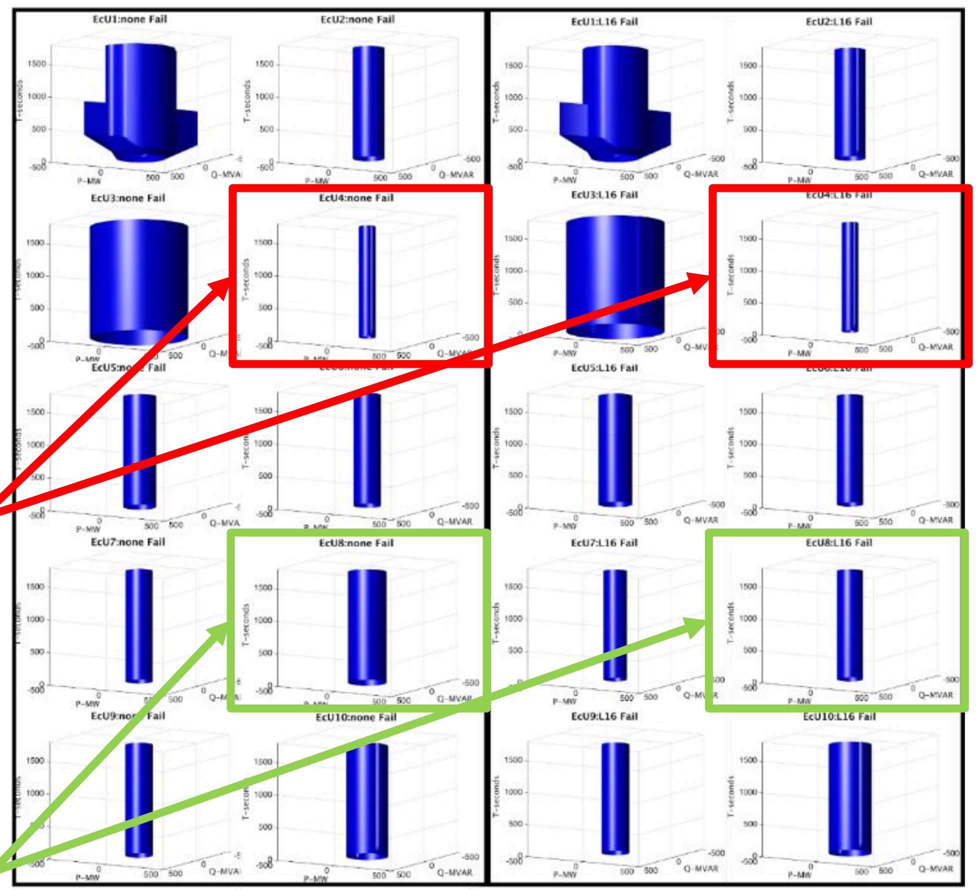
- The Electric Emergency Incident and Disturbance Report (OE-417) form for high wind related events filtered based on
  - Loss of 300 MW or more
  - Loss of 50,000 customer-hours or more
  - **Powerlines** and **transformers** are most associated component with large outages
- High wind event on the IEEE 14 bus system modeled in SAPHIRE
  - **Powerlines** and **transformers** exhibit the highest unavailability/hour (UA/h) that contributed to system-wide failure

# Significance: PowDDeR results for (a) nominal and (b) high wind




IEEE 14 bus segmented into economic units EcU1-10

(a) (b)

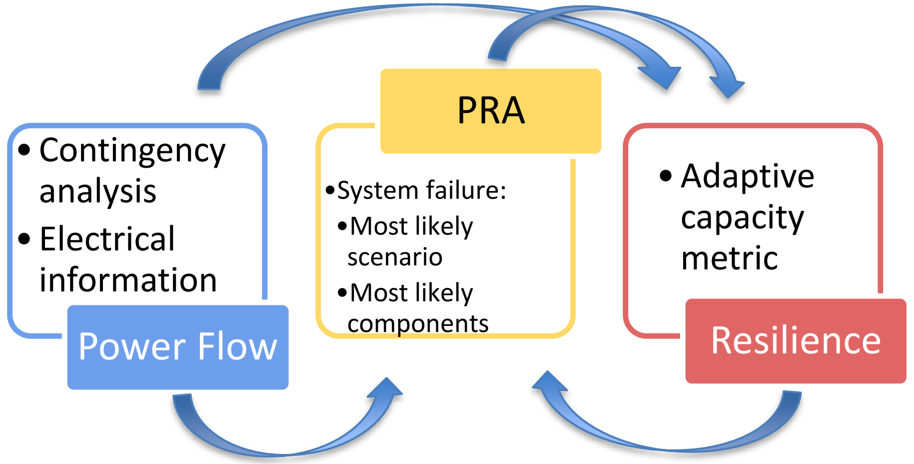



EcU4 most constrained

EcU8 largest change

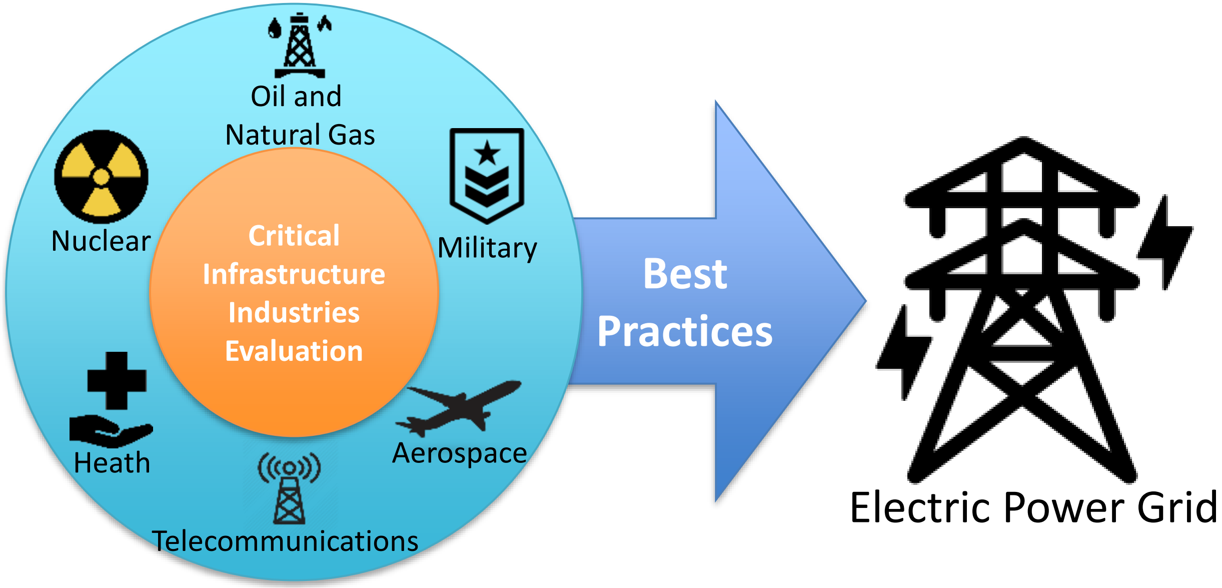
# Specific research questions being addressed

<u>Framework for evaluating power gird</u>



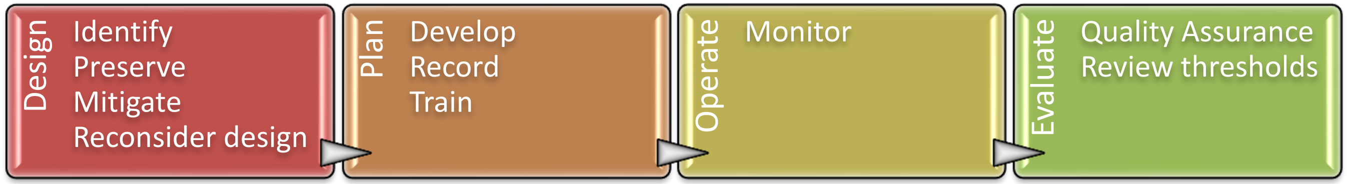

- Which component improvements in the power grid will provide the biggest benefit to resilience?
- What system upgrades provide the best improvements to resilience?

<u>Critical sector methodology comparison</u>



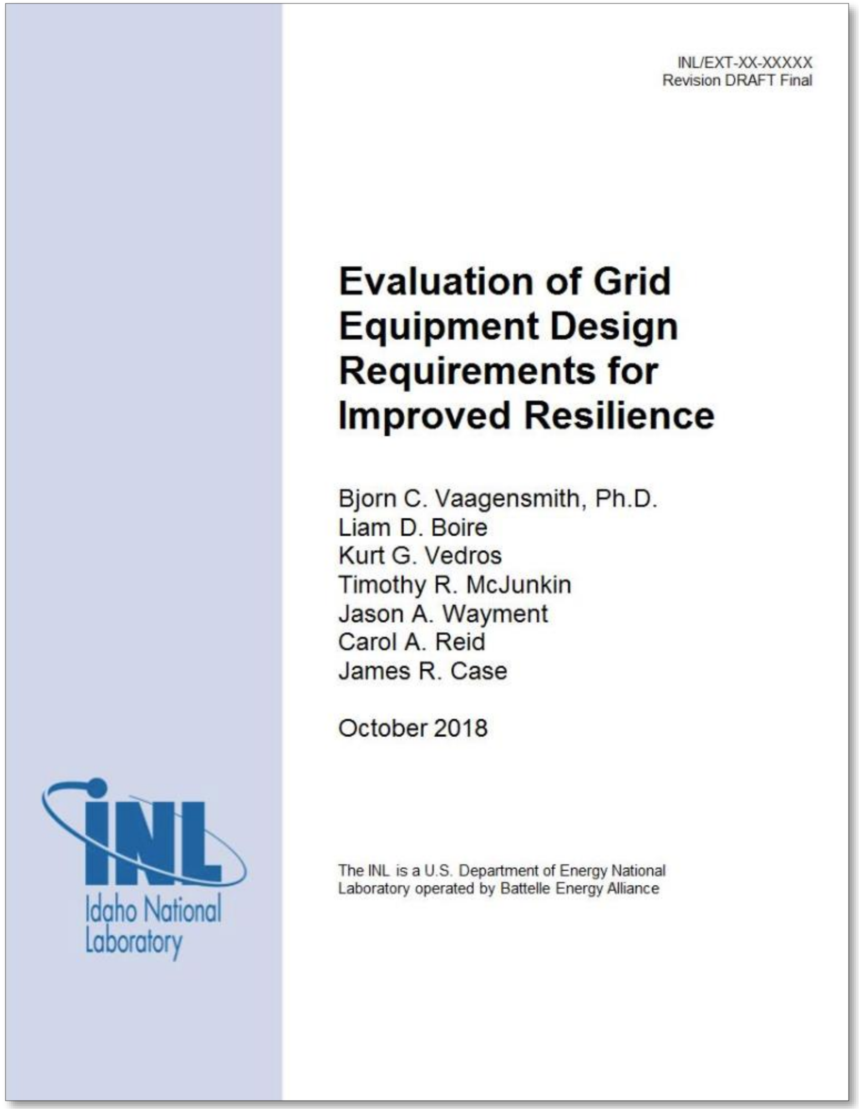

- What best practices from other critical infrastructure sectors can be leveraged to improve power grid resilience?

Common Best Practices Identified



# Project schedule, deliverables, and current status

- Budget expended: $500k
- Deliverables:
  - Final report
- Project status: completed


INL/EXT-XX-XXXXX
Revision DRAFT Final

**Evaluation of Grid Equipment Design Requirements for Improved Resilience**

Bjorn C. Vaagensmith, Ph.D.
Liam D. Boire
Kurt G. Vedros
Timothy R. McJunkin
Jason A. Wayment
Carol A. Reid
James R. Case

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Idaho National Laboratory

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# Next steps

- Partner with Utilities for further modeling framework validation

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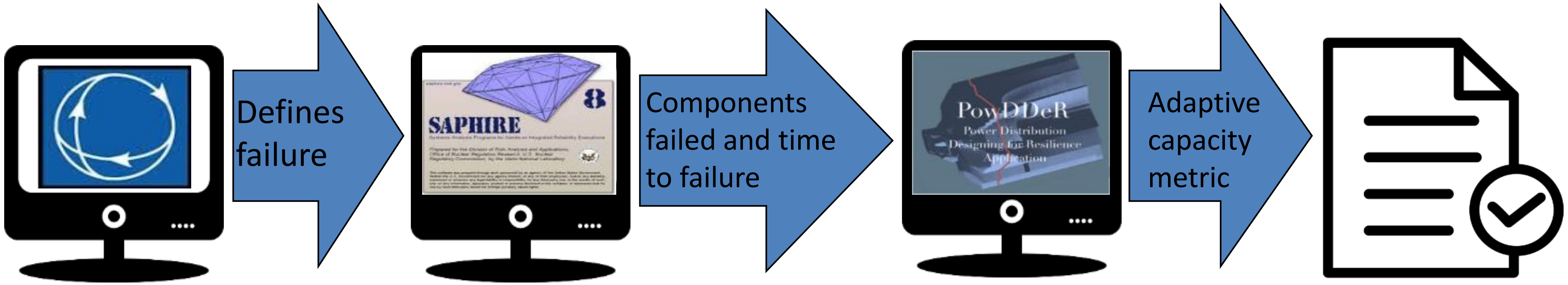
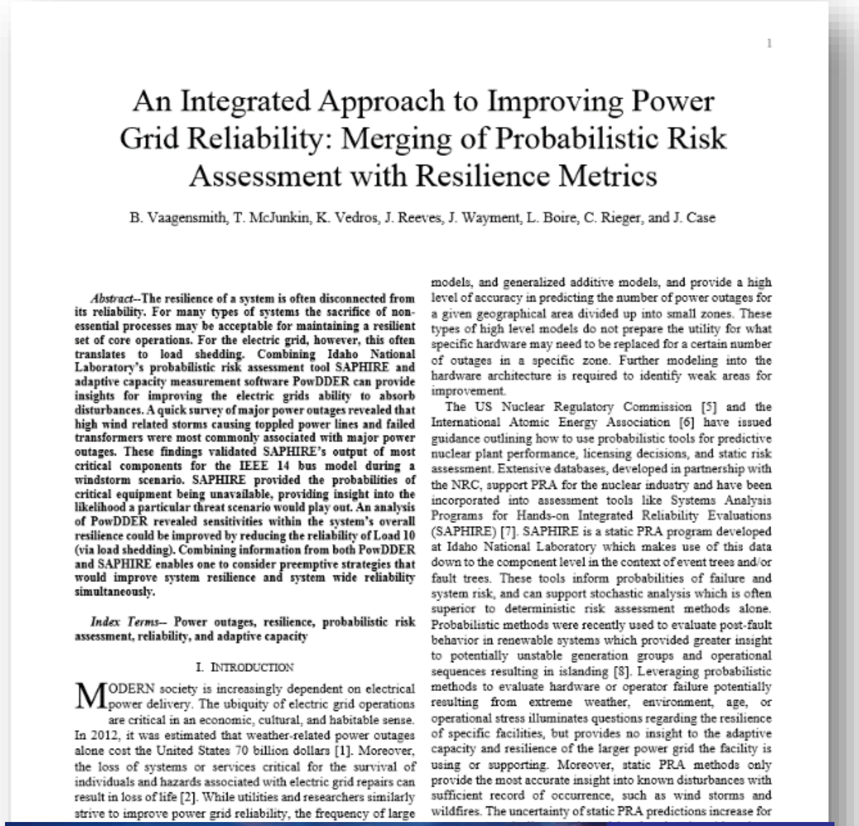
- Automate the communication between tool sets




Impact on grid performance

# Broader Impact

- Resilience Week paper
  - Won best infrastructure R&D paper
- Final Report shared with Duke Energy
- Wind Energy Technologies Office
  - MIRICAL project work package 3.2
- Provisional patent filed
  - Utility patent planned to be filed late summer
- Follow on work with Idaho Falls Power and Duke Energy
  - Further develop the tool to suit utilities needs



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An Integrated Approach to Improving Power Grid Reliability: Merging of Probabilistic Risk Assessment with Resilience Metrics

B. Vaagensmith, T. McJunkin, K. Vedros, J. Reeves, J. Wayment, L. Boire, C. Rieger, and J. Case

***Abstract*--The resilience of a system is often disconnected from its reliability. For many types of systems the sacrifice of non-essential processes may be acceptable for maintaining a resilient set of core operations. For the electric grid, however, this often translates to load shedding. Combining Idaho National Laboratory's probabilistic risk assessment tool SAPHIRE and adaptive capacity measurement software PowDDER can provide insights for improving the electric grids ability to absorb disturbances. A quick survey of major power outages revealed that high wind related storms causing toppled power lines and failed transformers were most commonly associated with major power outages. These findings validated SAPHIRE's output of most critical components for the IEEE 14 bus model during a windstorm scenario. SAPHIRE provided the probabilities of critical equipment being unavailable, providing insight into the likelihood a particular threat scenario would play out. An analysis of PowDDER revealed sensitivities within the system's overall resilience could be improved by reducing the reliability of Load 10 (via load shedding). Combining information from both PowDDER and SAPHIRE enables one to consider preemptive strategies that would improve system resilience and system wide reliability simultaneously.**

***Index Terms*-- Power outages, resilience, probabilistic risk assessment, reliability, and adaptive capacity**

I. INTRODUCTION

MODERN society is increasingly dependent on electrical power delivery. The ubiquity of electric grid operations are critical in an economic, cultural, and habitable sense. In 2012, it was estimated that weather-related power outages alone cost the United States 70 billion dollars [1]. Moreover, the loss of systems or services critical for the survival of individuals and hazards associated with electric grid repairs can result in loss of life [2]. While utilities and researchers similarly strive to improve power grid reliability, the frequency of large

models, and generalized additive models, and provide a high level of accuracy in predicting the number of power outages for a given geographical area divided up into small zones. These types of high level models do not prepare the utility for what specific hardware may need to be replaced for a certain number of outages in a specific zone. Further modeling into the hardware architecture is required to identify weak areas for improvement.

The US Nuclear Regulatory Commission [5] and the International Atomic Energy Association [6] have issued guidance outlining how to use probabilistic tools for predictive nuclear plant performance, licensing decisions, and static risk assessment. Extensive databases, developed in partnership with the NRC, support PRA for the nuclear industry and have been incorporated into assessment tools like Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) [7]. SAPHIRE is a static PRA program developed at Idaho National Laboratory which makes use of this data down to the component level in the context of event trees and/or fault trees. These tools inform probabilities of failure and system risk, and can support stochastic analysis which is often superior to deterministic risk assessment methods alone. Probabilistic methods were recently used to evaluate post-fault behavior in renewable systems which provided greater insight to potentially unstable generation groups and operational sequences resulting in islanding [8]. Leveraging probabilistic methods to evaluate hardware or operator failure potentially resulting from extreme weather, environment, age, or operational stress illuminates questions regarding the resilience of specific facilities, but provides no insight to the adaptive capacity and resilience of the larger power grid the facility is using or supporting. Moreover, static PRA methods only provide the most accurate insight into known disturbances with sufficient record of occurrence, such as wind storms and wildfires. The uncertainty of static PRA predictions increase for

# Contact Information

Work email: Bjorn.Vaagensmith@inl.gov
Work phone: 208-526-4008

Work email: Jesse.Reeves@inl.gov
Work phone: 208-526-2872

Work email: Carol.Reid@inl.gov
Work phone: 208-526-1902

Special thanks to other Team members:
Liam Boire, Timothy McJunkin, Kurt Vedros, Jekob Meng, Jason Wayment, Shawn West, and James Case