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PNNL-SA-121679

Testbed Capability at the Pacific Northwest National Laboratory

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The U.S. Department of Energy's National Laboratory system

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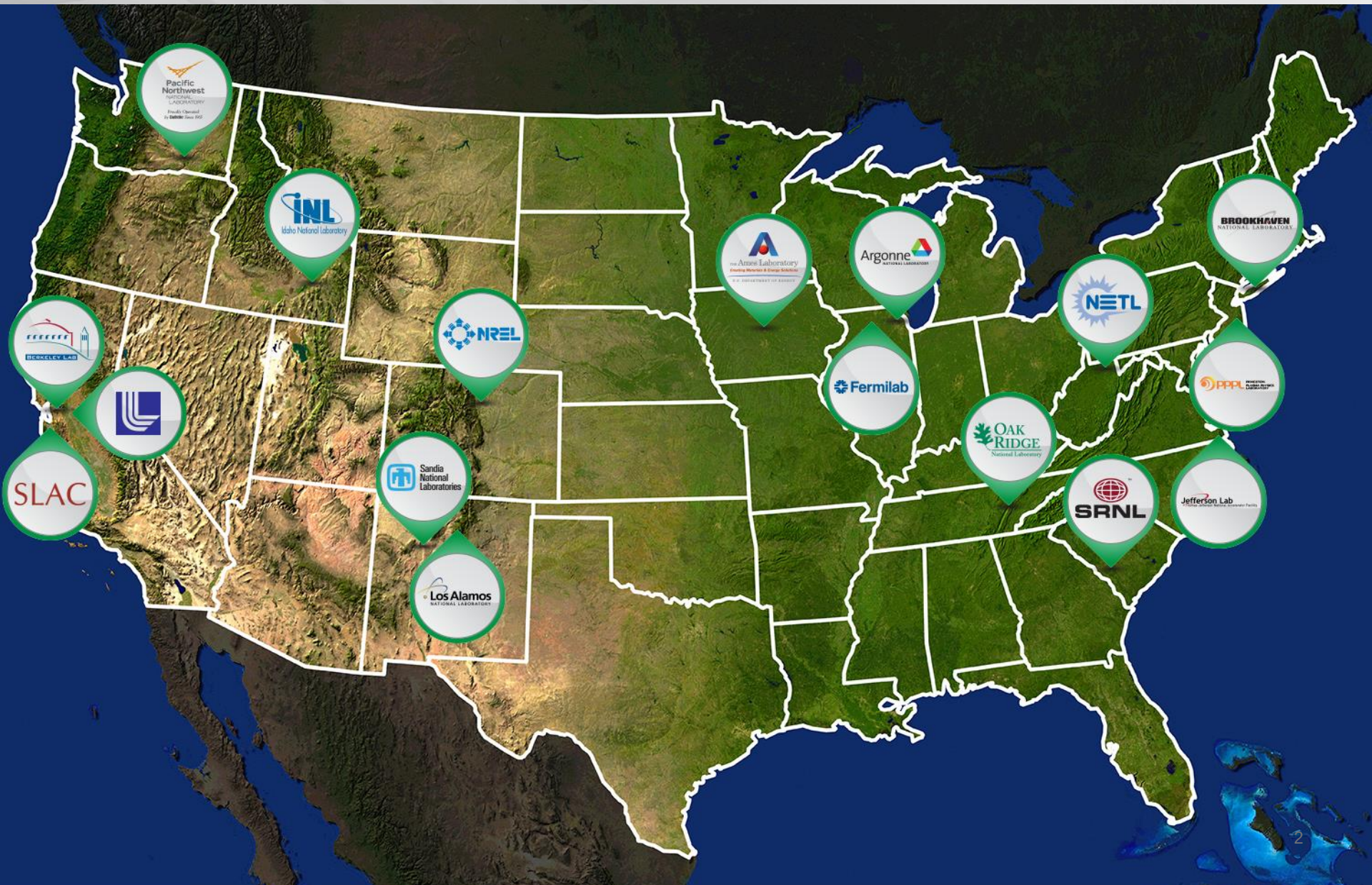

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Energy Mission Business Area:
Electricity Infrastructure

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- Electric power systems expertise
- Research and development of tools for enhancing electric power system reliability, security, and operational effectiveness
- Electricity Infrastructure Operations Center (EIOC), a national research test bed
- Real-time wide-area situational awareness of the electric grid through an integrated measurement system
- Analysis of large-scale renewable integration to the existing grid
- Advanced information, networking, and cyber security for reliability management services

Transforming the U.S. Energy System
PNNL's Electric Infrastructure Research Agenda

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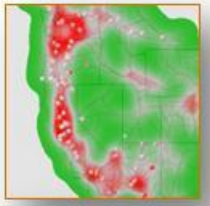
System Transparency – *Demonstrating enhanced measurement technologies for wide-area measurement, enhanced situational awareness, and real-time control*



Analytic Innovations - *Leveraging High-Performance Computing and new algorithms to provide real-time situational awareness and models for prediction and response*

End-Use Efficiency and Demand Response – *Making demand an active tool in managing grid efficiency and reliability.*

Renewable Integration – *Addressing variability and uncertainty of large-scale wind and solar generation and the complexities of distributed generation and net metering*

Energy Storage – *Defining the location, technical performance, and required cost of storage; synthesizing nanofunctional materials and system fabrication to meet requirements*

Cyber Security for Energy Delivery Systems – *Defining requirements for and developing technology to enhance secure control systems*

North American SynchroPhasor Initiative

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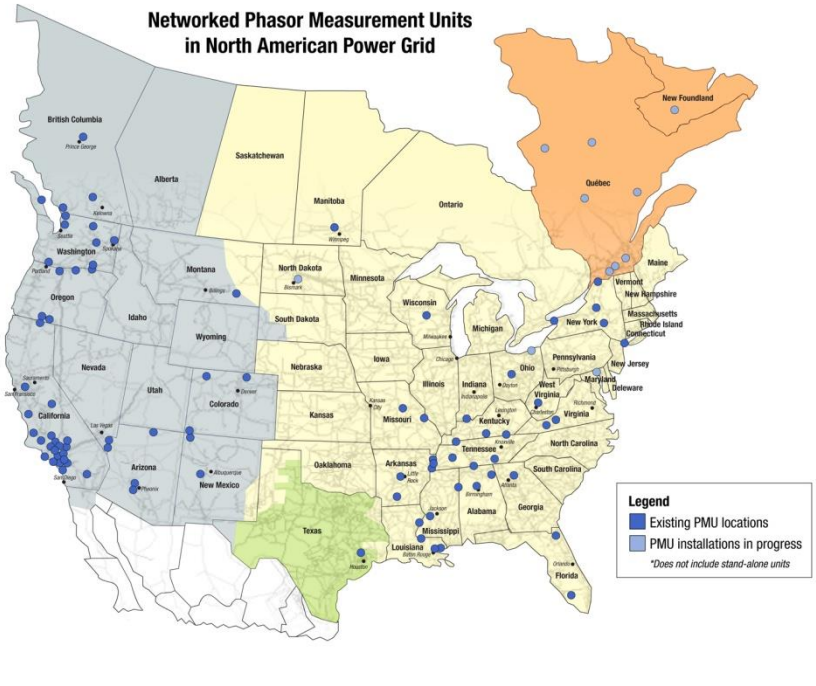
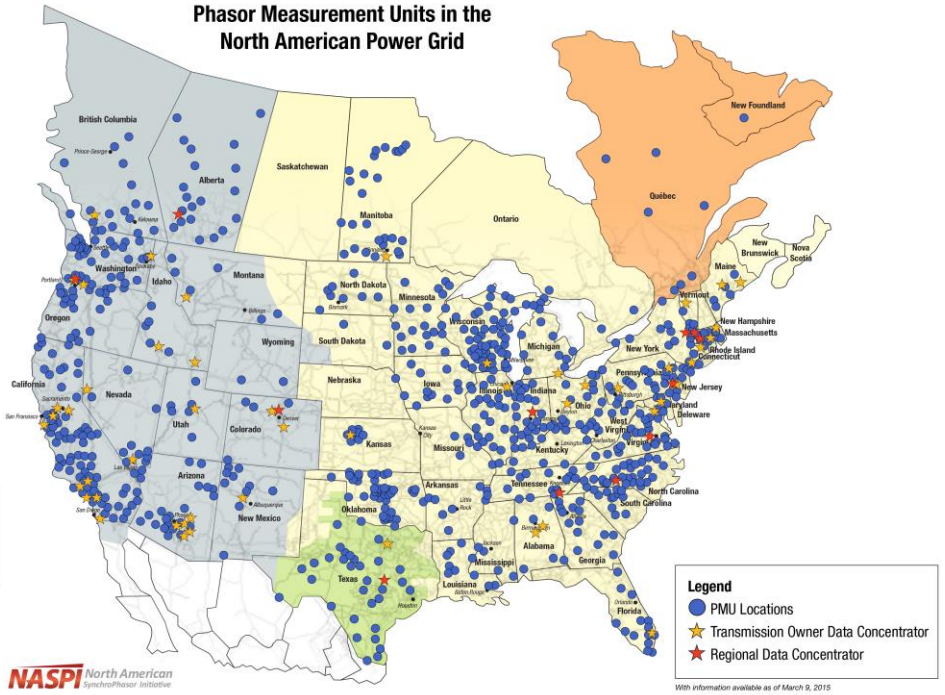
The U.S. Department of Energy (DOE) and EPRI are working together closely with industry to enable wide area time-synchronized measurements that will enhance the reliability of the electric power grid through improved situational awareness and other applications

April 2007



March 2015



"Better information supports better - and faster - decisions."

NASPI North American SynchroPhasor Initiative

EPRI ELECTRIC POWER RESEARCH INSTITUTE

PNNL Draws Upon Core Capabilities, Facilities, and Investments in Electricity Infrastructure

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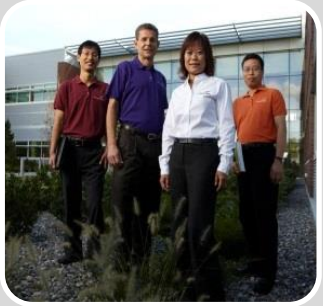

Staff Capabilities

- Power system operation, planning and security
- Power markets
- Demand response
- Renewable integration
- Cyber security
- Advanced analytic methods, HPC-based simulations, visualization

Physical Control Center (EIOC)

- Live PMU data
- PMU data archive
- PowerNET lab
- EMS/DMS displays
- T&D-level data displays
- Platform for tool evaluation, operator training

Cyber Security / Resilience Center (EICC)

- Live security data streams
- Visual analytics
- Co-located with classified assets that accelerate threat recognition and appropriate response
- Emergency Response
- Public / Private

Future Power Grid Initiative

- Networking and data management
- Advanced analytic methods and HPC approaches for real-time modeling and simulation
- Visualization and decision support
- Next Generation EMS
- Next Generation Simulation

Control of Complex Systems Initiative

- New Control Theory
- Generalizable using distributed systems
- Impacts buildings, power grid controls, buildings efficiency, cyber-security and high-performance computing
- New tools and technologies
- Testbeds

PNNL Testbed Capabilities Focused on National Electric Power Research Agenda

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Facilities

- Institutional Computing
- Systems Engineering Facility (Cyber)
- **Systems Engineering Building**
  - 15,000 sq ft, opened summer 2015
- Integrated multi-disciplinary research asset bringing together:
  - Power systems engineering
  - Two control rooms
  - Dedicated secure enclave for grid data
  - High performance computing
  - Interoperability lab to test software / hardware platforms
  - Power electronics high bay lab
  - Campus operations

BPA Administrator Elliot Mainzer, Deputy Secretary Elizabeth Sherwood-Randall, Senator Patty Murray, and Representative Dan Newhouse

System Engineering Building – the Heart of PNNL's Electricity Infrastructure Research

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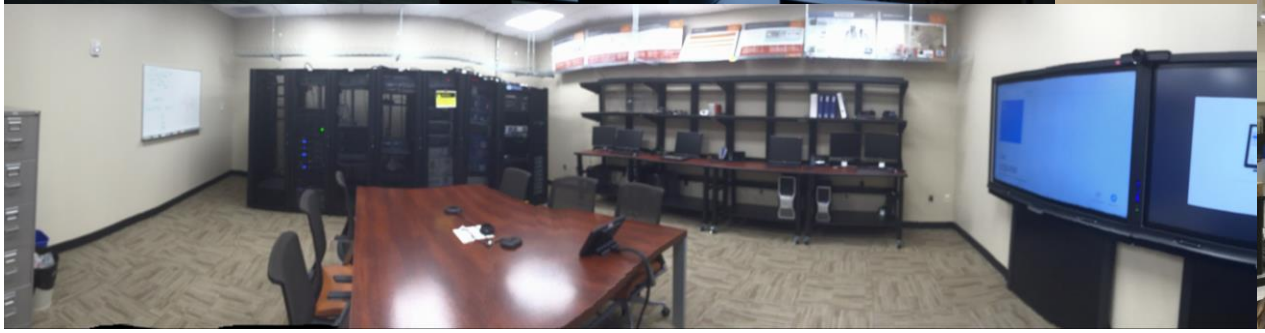

Visual Analytics of Massive Contingency Analyses for Real-Time Decision Support

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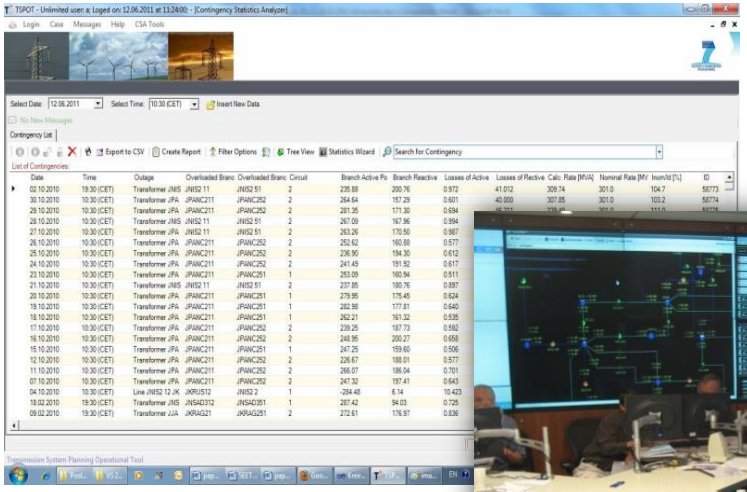
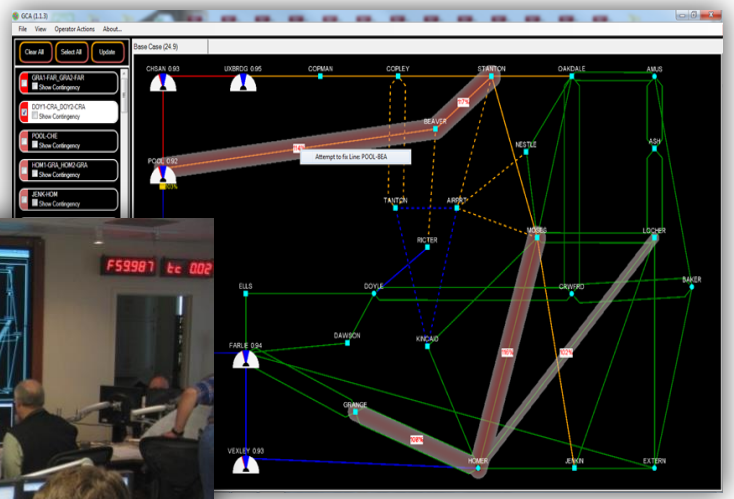
Current tabular format presents data, not information



New visualization tool displays prioritized risks



Graphical Contingency Analysis Tool (patent)

- **Easy-to-interpret visualization of power flow data**
- **Prioritizes areas of concern and recommends corrective actions**
- **Operators reported 30% improvement in emergency response**

GridOPTICS™ powerNET Functional Testbed

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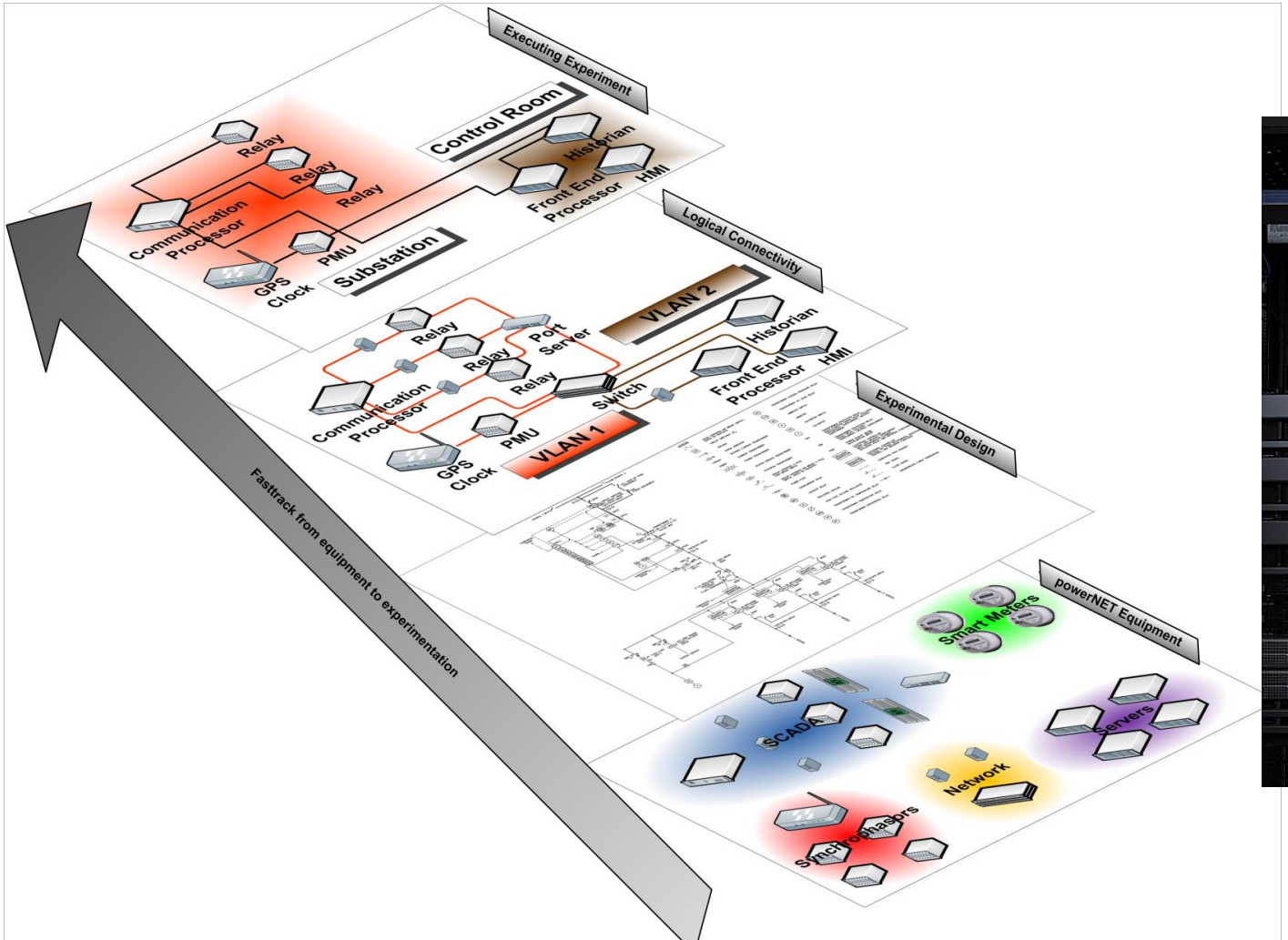
- Federated testing environment leveraging multiple organization's hardware and testing equipment



Federation in Various Forms

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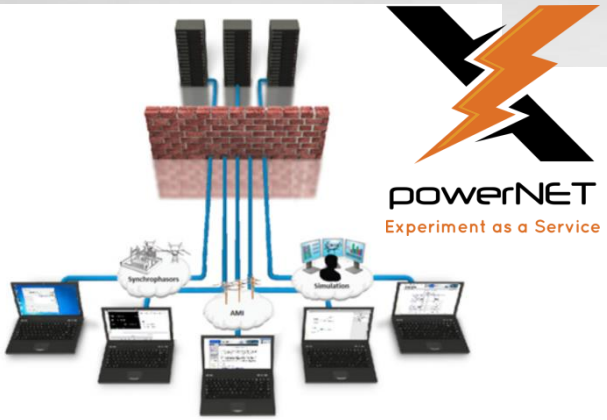
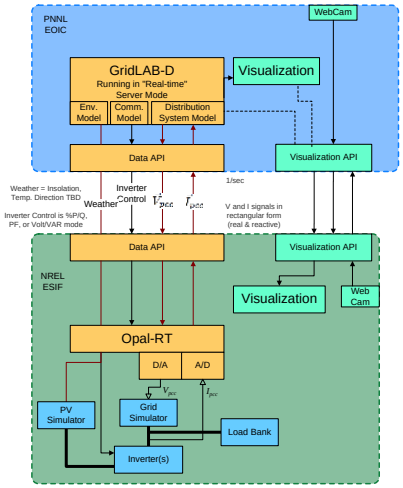
GridPACK™ VOLTTRON™ GridLAB-D FNCS

Encouraging collaboration and acceptance through open platforms



Remotely accessible experimental user facility for power system research

Evaluating large-scale, interconnected systems through co-simulation



Hardware-in-the-loop across organizational boundaries

Open-Source Software Tools as Foundation of GridOPTICS™

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GridPACK™

Software framework

–

Enables access to computers with more memory and processing power

–

Provides for simulation of models that contain vast networks and high levels of detail

VOLTTRON™

Distributed control and sensing software platform

–

Makes it possible to build applications to more efficiently manage energy use

FNCS

Framework for Network Co-Simulation: a federated co-simulation platform

–

Merges data simulators with distribution and transmission simulators to model and design smart grid tools & control

GOSS

GridOPTICS™ Software System—a middleware framework

–

Integrates grid applications with multiple sources of data; enhances development of grid management applications

Inter-Laboratory Collaboration

- Open-source model encourages utilization, industry transformation
  - New capabilities introduced by vendors, utilities, other national labs (PNNL manages and validates)
  - EPRI's [Open]DSS declared open source
  - Utilities starting to buy-in, direct use & consultant-based
  - Spurring vendor capabilities
- Encourage integration with other tools
  - Co-simulation via FNCS (an open-source PNNL tool) - communications, buildings, transmission, wholesale
- Collaborative development projects with multiple national labs
  - ORNL, NREL, SNL, LBNL, ANL
- GridLAB-D currently used by at least 9 national labs, dozens of utilities, many universities

Collaboration

Encouraging collaboration through transparency

NREL
Sandia National Laboratories
OAK RIDGE National Laboratory
Argonne NATIONAL LABORATORY
INL Idaho National Laboratory
Pacific Northwest NATIONAL LABORATORY
Lawrence Berkeley National Laboratory
NIST National Institute of Standards and Technology U.S. Department of Commerce
Lawrence Livermore National Laboratory

Testing Vulnerabilities Associated with Satellite Clocks for Precision Timing Applications in the Power System

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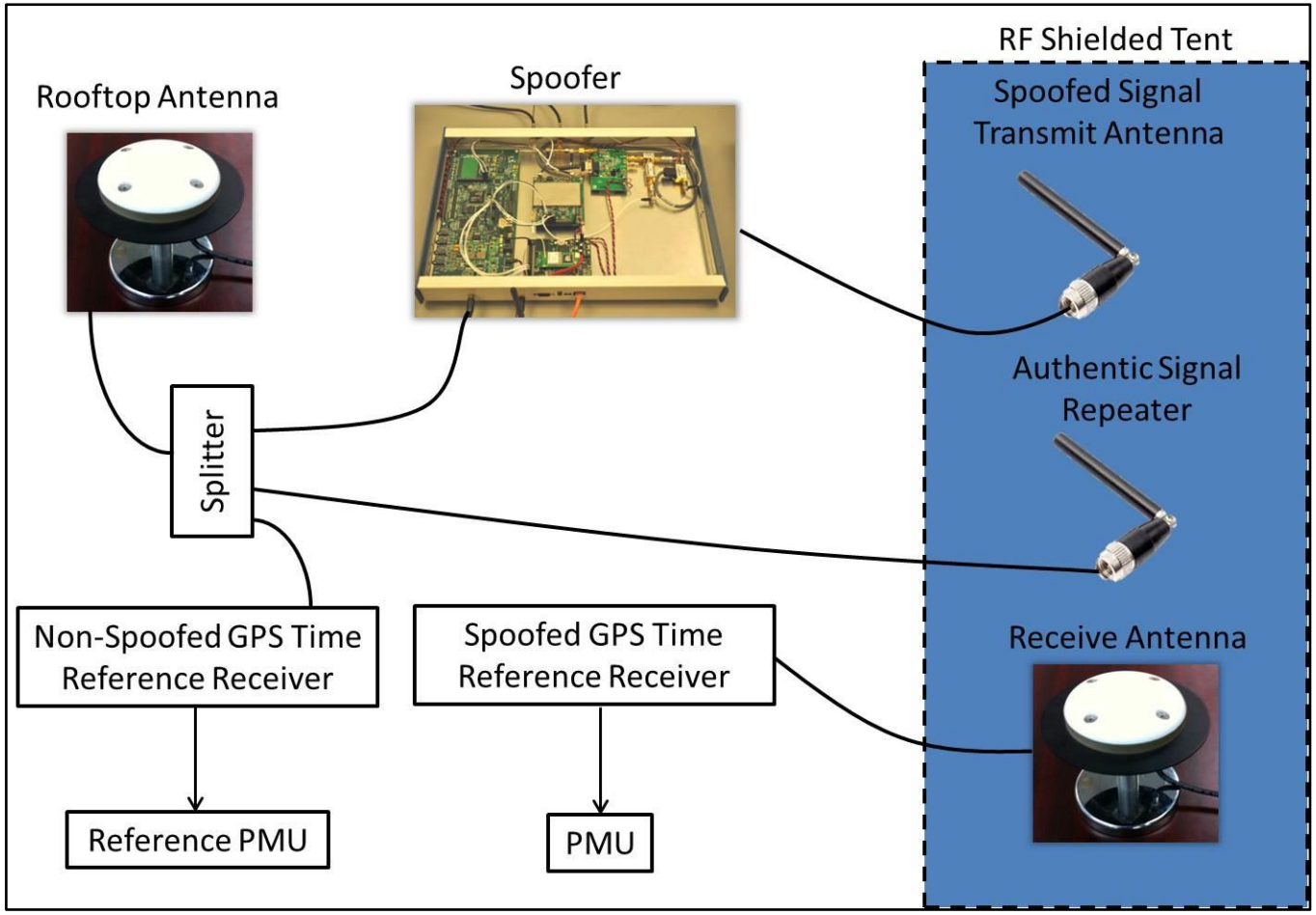
Test Objectives:

- Determine the susceptibility of GPS satellite clocks to spoofing that could undermine the accuracy of Phasor Measurement Units (PMU)
- Tests carried out at the PNNL Electricity Infrastructure Operations Center (EIOC) December 2011 with Northrop Grumman and University of Texas-Austin
- Three different satellite clocks were utilized in the testing

Schematic of the Test Setup



RF Shielded Tent

Spoofing Test Result: Impacting the Phase Angle Measurement by Manipulating the Time Reference

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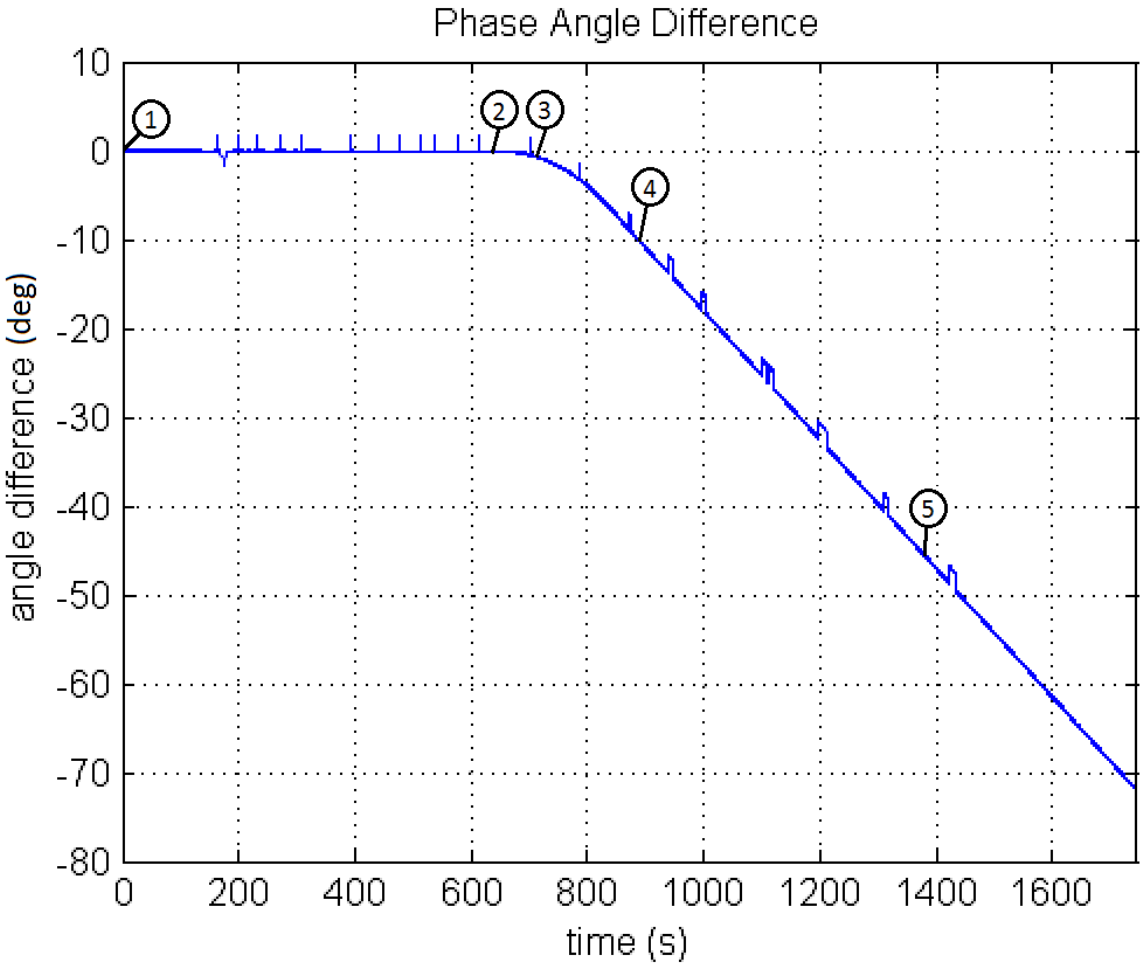

Conclusions

- All three satellite clocks that we tested were susceptible to GPS spoofing
  - Some differences in the rate of change that could be implemented (defeating the internal error checking algorithms)
  - Some differences in how the clocks responded when the spoofing signal was turned off
- Recommending an alternative method for time synchronization associated with control applications that require secure timing
- The North American SynchroPhasor Initiative (NASPI) Time Synchronization Task Force is investigating various alternatives and recommended practices


Mission
We transform the world through courageous discovery and innovation.
Vision
PNNL science and technology inspires and enables the world to live prosperously, safely and securely.
DISCOVERY in Action
CREATIVITY
integrity
courage
Values
Impact
COLLABORATION
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