Overview of NIST and the Engineering Laboratory

Dr. Howard Harary, Director
Engineering Laboratory
### NIST at a Glance

<table>
<thead>
<tr>
<th>Icon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="People" /></td>
<td><strong>3400+ Employees</strong></td>
</tr>
<tr>
<td><img src="image2.png" alt="Wrench and Hammer" /></td>
<td><strong>Focus on Advanced Manufacturing</strong></td>
</tr>
<tr>
<td><img src="image3.png" alt="Location" /></td>
<td><strong>2 Campuses</strong> (Gaithersburg, MD [HQ], Boulder, CO)</td>
</tr>
<tr>
<td><img src="image4.png" alt="Atom" /></td>
<td><strong>Focus on Quantum Science</strong></td>
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<tr>
<td><img src="image5.png" alt="Award" /></td>
<td><strong>4 Nobel Prizes</strong></td>
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<tr>
<td><img src="image6.png" alt="Satellite" /></td>
<td><strong>Focus on Advanced Communications</strong></td>
</tr>
<tr>
<td><img src="image7.png" alt="Bar Graph" /></td>
<td><strong>400+ Business Using NIST Facilities</strong></td>
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<tr>
<td><img src="image8.png" alt="Lock" /></td>
<td><strong>Focus on Cybersecurity</strong></td>
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<tr>
<td><img src="image9.png" alt="People" /></td>
<td><strong>3800+ Associates &amp; Facilities Users</strong></td>
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<tr>
<td><img src="image10.png" alt="Fire" /></td>
<td><strong>Focus on Disaster Resilience</strong></td>
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<tr>
<td><img src="image11.png" alt="Map" /></td>
<td><strong>9 Collaborative Institutes</strong></td>
</tr>
</tbody>
</table>
NIST Laboratory Programs

**Metrology Laboratories**
- Driving innovation through Measurement Science and Standards

**Technology Laboratories**
- Accelerating the adoption and deployment of advanced technology solutions

**National User Facilities**
- Providing world class, unique, and cutting-edge research facilities
NIST Mission

To promote U.S. innovation and industrial competitiveness by advancing **measurement science**, **standards**, and **technology** in ways that enhance economic security and improve our quality of life.

### measurement science
Creating the experimental and theoretical tools – methods, metrics, instruments, and data – that enable innovation.

### standards
Disseminating physical standards and providing technical expertise to documentary standards that enable comparison, ensure interoperability, and support commerce.

### technology
Driving innovation through knowledge dissemination and public-private partnerships that bridge the gap between discovery and the marketplace.
Measurements are critical...

To commerce

“If you know how to measure something, you can design it, compare it, understand it, and improve it.”

George Washington, State of the Union Address, 1790

To innovation

NIST measurement science provides the foundation for innovation in every industry and economic sector, from manufacturing to health care to defense

Up to 92% of U.S. exports affected by standards/technical regulations

And to international trade

NIST Illustrated, https://youtu.be/2j9BGVkbzS4
NIST Laboratory Products and Services

Serving industry and other stakeholders in the U.S. and globally

• 1200+ Standard Reference Material (SRM) products
• 100+ Standard Reference Data (SRD) products
• 600+ measurement services
• 800+ accreditations of testing and calibration laboratories per year
NIST Documentary Standards

Providing support to industry and government for voluntary standards development

NIST’s unique role

- NIST coordinates standards policy among federal agencies (National Technology Transfer and Advancement Act, 1996)
- NIST Director is President’s principal advisor on standards (American Innovation and Competitiveness Act, 2016)
- NIST’s laboratory expertise provides measurement-based and unbiased data to improve decision-making in standards bodies

Expert participation

- 400+ NIST technical staff in 100+ standard committees
- Leadership in international standards bodies such as ASTM, IEEE, ISO, IEC

NIST studies of fire behavior led to life-saving changes in U.S. building codes

NIST robotics standards are catalyzing U.S. manufacturing automation transformation

Standards and assessments for public safety communications are transforming emergency response
NIST Laboratory Programs

- **Metrology Laboratories**
  - Material Measurement Laboratory
  - Physical Measurement Laboratory
  - Engineering Laboratory
  - Information Technology Laboratory
  - Communication Technology Laboratory

- **Technology Laboratories**
  - Center for Nanoscale Science and Technology
  - NIST Center for Neutron Research

**Metrology Laboratories**
Driving innovation through Measurement Science and Standards

**Technology Laboratories**
Accelerating the adoption and deployment of advanced technology solutions

**National User Facilities**
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EL Mission

To promote U.S. innovation and industrial competitiveness by advancing **measurement science**, **standards**, and **technology for engineered systems** in ways that enhance economic security and improve our quality of life.

- **measurement science**: Creating the experimental and theoretical tools—methods, metrics, instruments, and data—that enable innovation.
- **standards**: Disseminating physical standards and providing technical expertise to documentary standards that enable comparison, ensure interoperability, and support commerce.
- **technology**: Driving innovation through knowledge dissemination and public-private partnerships that bridge the gap between discovery and the marketplace.
Engineering Laboratory Goals

- Resilience
- Smart Manufacturing
- Cyber Physical Systems
- Energy
Engineering Laboratory Goals

- Resilience
  - Community Resilience
  - Fire Risk Reduction
  - Earthquake
  - Structural Performance
  - Engineered Materials

- Smart Manufacturing

- Cyber Physical Systems

- Energy
Engineering Laboratory Goals

- Resilience
- Smart Manufacturing
  - Additive Manufacturing
  - Robotic Systems
  - Systems Design/Analysis
  - Ops Planning/Control
- Cyber Physical Systems
- Energy
Engineering Laboratory Goals

- Resilience
- Smart Manufacturing
- Cyber Physical Systems
  - Smart Grid
  - Cyber Physical Systems
- Energy
Engineering Laboratory Goals

- Resilience
- Smart Manufacturing
- Cyber Physical Systems
- Energy
  - Embedded Intelligence in Buildings
  - Net Zero Energy, High Performance Buildings
Engineered Systems Research

Unique Engineered Systems Research

• Cyber-Physical Systems and Smart Grid testbeds for “smart” everything
• Models and measurements of materials, buildings, and other infrastructure for disaster- resilient communities; Fire models and data for improved, performance-based building codes
• Robotics, control systems, and digital data exchange standards for smart manufacturing infrastructure
• Sensing systems and data to enable net zero energy buildings while maintaining air quality

Unique Facilities and Functions

• Smart Grid Interoperability Panel
• National Fire Research Laboratory
• Robotics Test Facility
• Net-Zero Energy Residential Facility
• National Construction Safety Team
• Disaster investigations, studies and interagency research coordination
• Community Resilience Center of Excellence
Thank you
Smart Grid and Cyber-Physical Systems Programs

Dr. Chris Greer
Director, Smart Grid and Cyber-Physical Systems Program Office
Engineering Laboratory, NIST
christopher.greer@nist.gov
Overview

• Review Agenda
• SG & CPS Program Vision
• CPS Program Components
Agenda – Day 1

10:00 AM BREAK

10:20 AM Smart Grid Program Update
Avi Gopstein

11:50 PM LUNCH

1:00 PM Ethics Briefing
Eric Johnson

1:30 PM Smart Grid Interoperability and Building to Grid Integration
Steve Bushby

1:50 PM Smart Grid Cybersecurity
Nelson Hastings

2:10 PM Grid Architecture and System Dynamics
DJ Anand

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2:50 PM SEPA Update
Sharon Allan

3:10 PM Discussion of Plans for NIST Framework and Roadmap for
Smart Grid Interoperability Standards, Release 4.0
All

4:50 PM Wrap Up
Chris Greer

5:00 PM Adjourn for the day 6:00 PM

Optional Dinner
Agenda – Day 2

August 18, 2017

8:30 AM  Convene in Building 101

8:45 AM  Smart Grid Interoperability Testbed Tour
          All

10:00 AM  Discussion on NIST Smart Grid Research
          Portfolio and Future Priorities
          All

11:30 AM  Public Comments

11:45 AM  Planning for Next Meeting and Wrap Up
          Chris Greer

12:00 PM  Adjourn
## FY17 Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>$M</th>
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<tbody>
<tr>
<td>Cyber-Physical Systems</td>
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<td>Smart Grid</td>
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<tr>
<td><strong>Total</strong></td>
<td>$11.7</td>
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*Not included: Associates, contractors, other NIST, Federal, corporate, university partners*

## Core Personnel

<table>
<thead>
<tr>
<th>Category</th>
<th>FTE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research</td>
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<tr>
<td>Support</td>
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</tr>
<tr>
<td>Management</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>11</td>
</tr>
</tbody>
</table>
SG & CPS Program Strategy

Foundations

Knowledge Theory
Collaboration
Hypotheses
Experiment

Experiment/Test Bed

Applications
Cyber-Physical Systems (CPS) comprise interacting digital, analog, physical, and human components engineered for function through integrated physics and logic.

- Examples include a smart grid, a self-driving car, a smart manufacturing plant, an intelligent transportation system, a smart city, and Internet of Things (IoT) instances connecting new devices for new data streams and new applications.
- Common notions of IoT have emphasized networked sensors providing data streams to applications.
- CPS concepts complete these IoT notions, providing the means for conceptualizing, realizing and assuring all aspects of the composed systems of which sensors and data streams are components.

The Framework for Cyber-Physical Systems was released by the NIST CPSPWG on May 26, 2016
Foundations

- **NIST Cyber-Physical Systems (CPS) Framework**
  NIST CPS Public Working Group (5 working groups, led by industry, academia and NIST co-chairs) produced CPS Framework, published as NIST SP 1500-201 and 1500-202.
CPS vs IoT by Example: Home Energy Management System

- Cyber Security
- Sensors
- Motion Model
- Economic Model
- Actuators

Data

Networks

Hardware

Software

- Compute
  - Platforms
  - Functions

Physical Interaction
- Logical Interaction
- Dependency

IoT

CPS

Cyber

Security

Motion
Model

Economic
Model

Actuators

Sensors

IN

OUT

IN

OUT

IN

OUT
Experiment/Testbed

UCEF 1.0.0-ALPHA

Kickoff Workshop

Smart Grid and Cyber-Physical Systems Program Office
Engineering Laboratory
National Institute of Standards and Technology
July 27, 2017
UCEF Federated Testbed Architecture

• Integrative
  • Able to combine unlike things
    • sectors such as energy, transportation, ...
    • real and virtual components such as simulations, external systems, hardware in the loop
    • technologies including Java, C++, MatLAB, LabVIEW, ...

• Reconfigurable and Reproducible
  • Composable experiments with the “federate” interface model
  • Experiment orchestration language, Courses of Action (COA)
  • Communications and other co-simulation

• Scalable
  • Small sets of components up to large collections

• Usable
  • Partition experiment design from experiment component design
  • Allows designer focus on component implementation
  • Proprietary components can be exposed by designed experiment interfaces
Applications

Global City Teams Challenge

GLOBAL CITY TEAMS CHALLENGE EXPO 2017
AUGUST 28-29 | WASHINGTON DC
GCTC: Over 160 Participating Cities and Communities

Examples:
- Saitama (Japan)
- Shirahama (Japan)
- Portland, OR
- Newport News, VA
- Greenville, SC
- Raleigh, NC
- Montgomery County, MD
- Winooski, VT
- San Mateo County, CA
- New York, NY
- Washington, DC
- Columbus, OH
- Kansas City, MO
- Nashville, TN
- Austin, TX
- Amsterdam (Netherlands)
- Genova, Perugia (Italy)
- Coruna, Valencia (Spain)
- Saint-Quentin (France)
- Abuja City, Obia-Akpor City (Nigeria)
- Busan, Seoul, Daegu (Korea)

And, over 400 companies, universities, non-profits, government agencies

GCTC 2016 Partners
**LinkNYC by City Bridge**

First-of-its-kind communications network that will bring the fastest available municipal Wi-Fi to millions of New Yorkers and visitors.

**StormSense Project**

Forecasting Flooding from Storm Surge, Rain, and Tide.

**Greenville Smart City Vision**

- Everything connected via AT&T and Internet.
- Underground switchyards, secure telecommunications.
- Automated/Intelligent EV buses connecting communities.
- Smart grid integrating solar and wind energy.
- Traffic lights controlled by solar panels.
- Automated EV home charging systems.
- Innovative charging & power management by Masdar Systems.
- Fuel cell powered community microgrids.
- Transportation hubs with Enterprise CarShare.
- 5G shared vehicle connecting communities.

**SMART MOBILE OPERATION: OSU TRANSPORTATION HUB (SMOOTH)**

**First Mile/Last Mile Solutions**

- On-demand autonomous vehicles will move passengers the first mile to the bus stop and the last mile from the bus stop to傍晚 parked vehicles.
- Scheduled or on-demand vehicles will move passengers through a defined area within OSU campus through roads and pedestrian areas, top priority.
- The vehicles will:
  - use automated driving technology.
  - use 5G communication for convoy driving.
  - be deployed with real-time ridesharing technologies utilizing mobile or pedestrian areas.

**automated systems**

- SMOOTH will require a robust vehicle and pedestrian systems.
- Smartphone applications will be developed to schedule and track the on-demand autonomous vehicles.

**Pirates on your side**

- University of Virginia
- The Ohio State University
- Virginia Tech
- Virginia Beach
- Norfolk
- Hampton
- Portsmouth
- Chesapeake
- Williamsburg
- Newport News
- National Park Service
- VDH

**AUTOMATING THE FIRST AND LAST MILES**

- Ohio State University – Center for Automotive Research
- City of Columbus
- Mid-Ohio Regional Planning Commission (MORPC)
- Team ARCO

- Location: Columbus, Ohio
Applications - IoT-Enabled Smart City Framework

• Smart City technologies are being developed and deployed at a rapid pace and most smart city deployments are custom solutions.

• A number of architectural design efforts are underway worldwide but have not yet converged.

• NIST and its partners convened a public working group to distill a common set of architectural features from these architectural efforts and city stakeholders.

Goal: Facilitate the development of incremental and composable Smart Cities
Pivotal Points of Interoperability (PPI)

Independent technology deployments

Potentially large distance to interoperability

With Pivotal Points of Interoperability

- PPI
  - e.g. REST APIs

- PPI
  - e.g. TLS 1.2

- PPI
  - e.g. IPv6 address

Minimize distance to interoperability
- e.g. Convert XML to JSON

Application Diversity
Agenda – Day 1

10:00 AM BREAK

10:20 AM Smart Grid Program Update
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11:50 PM LUNCH

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Optional Dinner
Avi Gopstein
Smart Grid Program Manager
Smart Grid and Cyber-Physical Systems Program Office
National Institute of Standards and Technology
U.S. Department of Commerce

August 17, 2017
NIST’s Mission

To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.
NIST has “primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems…”
SGCPS Program Strategy

**Foundations**
- SG Framework

**Experiment/Test Bed**
- SG Research
- SG Test Bed

**Applications**
- SG Coordination
- TE Challenge
Smart Grid Program Overview

**Cooperation**
- Standards development
- SGIP / SEPA
- Interoperability Framework V4

**Experimental facilities**
- Smart Grid Testbed
- Testbed commissioning & integration
- Expanding capabilities

**Research**
- Integrated research, common objectives
- Monitoring and Control
- Cybersecurity
- Communications & timing
- Operations and economics
Smart Grid Program

Program Manager: Avi Gopstein

FY17 Allocation

<table>
<thead>
<tr>
<th>Description</th>
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<tr>
<td>Program*</td>
<td>$4.28 M</td>
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<tr>
<td>SGIP/SEPA</td>
<td>$1.20 M</td>
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<tr>
<td>Transfer to other NIST labs</td>
<td>$3.06 M</td>
</tr>
<tr>
<td>Total</td>
<td>$8.54 M</td>
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</table>

Objective: To improve the efficiency, sustainability, economics, and resiliency of the nation’s electric grids by developing and demonstrating advances in measurement science to improve grid interoperability and facilitate the use of the distribution grid as an enabling platform for modern energy services.
# NIST Smart Grid Program – Budgetary Structure

## Smart Grid Program

<table>
<thead>
<tr>
<th>Experimental Facilities</th>
<th>Coordination</th>
<th>Research</th>
</tr>
</thead>
</table>

### Smart Grid Test Bed
- Smart Grid System Testbed Facility (SL SGP) - Boynton
- Power Conditioning Systems for Renewables, Storage, and Microgrids (PML) - Hefner

### National Coordination + Strategy
- Smart Grid Secretariat (EL SGP) - Gopstein
- Smart Electric Power Alliance (EL SGP) - Nguyen
- Smart Grid Testing and Certification (EL SGP) - Nguyen

### Smart Grid Projects
- Cybersecurity for Smart Grid Systems (ITL) - Hastings
- Smart Grid Communication Networks (CTL) - Griffith
- Smart Grid Communication Networks (ITL) - Gharavi
- Precision Timing for Grid Systems (ITL) - Li-Baboud
- Wide-area Monitoring and Control of Smart Grid (PML) - FitzPatrick
- Electromagnetic Compatibility (CTL) - Ladbury
- Building Integration with Smart Grid (EL) - (*not incl. $300k EIB) - Holmberg/Gopstein
- Quantifying Key Economic Issues in the Smart Grid (EL AEO) - O'Fallon
COORDINATION
External Coordination: Frameworks

NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0

Office of the National Coordinator for Smart Grid Interoperability

NIST Special Publication 1108

NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0

Office of the National Coordinator for Smart Grid Interoperability, Engineering Laboratory in collaboration with Physical Measurement Laboratory and Information Technology Laboratory

NIST Special Publication 1108R2

NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0 in collaboration with Quantum Measurement Division, Semiconductor and Dimensional Metrology Division, Electromagnetics Division, Physical Measurement Laboratory and Advanced Network Technologies Division and Computer Security Division, Information Technology Laboratory

NIST Special Publication 1108r3

This publication is available free of charge from http://dx.doi.org/10.6028/NIST.SP.1108r3
Interoperability Framework V1

NIST Special Publication 1108

NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0

Office of the National Coordinator for Smart Grid Interoperability

2010

Identified 25 standards

Introduced grid domains

Explored network information exchange

... and cyber
Interoperability Framework V1

Smart Grid Interoperability Panel

• Created SGIP as public-private partnership
• Became a major force alongside NIST
  – Priority Action Plans
    • Working Groups formed to address gaps
    • Targeted deliverables
      – map to existing standards
      – new standards
  – Catalog of Standards
    • 81 standards
    • navigation tool
• Detailed discussion later today
Interoperability Framework – Moving forward

• Subsequent frameworks updated and expanded on issues
• Significant changes across industry since 2014
• To be continued…
Every Research Project

• Successes:
  – NEMA Interoperability Process Reference Manual (IPRM)
  – IEEE Std. 21451-001-2017: Recommended Practice for Signal Treatment Applied to Smart Transducers
  – Published ANSI C12.20 standard on electricity metering requirements, including harmonics (WAMC)
  – International ballots initiated for approval of OpenADR 2.0 (enables demand response) (BISG)
  – ASHRAE/NEMA Facility Smart Grid Information Model (FSGIM) standard adopted by ISO (BISG)
  – Published IEC PC118 Technical Report 62939 TR Ed.1 Smart Grid User Interface (BISG)
  – Contributed Green Button utility tariff model to the CIM (BISG)
  – SGIP PAP 12 / IEEE 1815.1-2016 standard for exchanging information between networks (WAMC)

• Plans:
  – IEEE 1547.1 test specifications for DER including smart inverters (PCS)
  – IEEE / IEC 61850-9-3 Precision Time Protocol Power Profile Conformity Assessment Steering Committee – test plan and methodology development (SGTC)
  – IEEE Microgrid Controller standards 2030.7 & 2030.8 (PCS)
  – Smart inverter functions required by IEEE 1547 are defined in IEEE 61850-7-420 and implemented in IEEE 2030.5 (PCS)
  – Continue promoting the international adoption of US/SGIP standards (SGNC)
  – Joint IEC/IEEE 60255-118-1 PMU standard (WAMC)
  – IEC 60859-13 Standalone Mus (WAMC)
• Establishes a standard approach to understanding and evaluating interoperability for device manufacturers
• Developed under the SGIP SGTCC and NEMA Distribution and Automation section
• Chaired by NIST’s Cuong Nguyen and NEMA’s Steve Griffith
Standards & NIST: IEEE Inverter & Microgrid Controller

### PAP 7: DER/Electric Storage Interconnection Guidelines

- **Task 0: Scoping Document**
  - Prioritized timeline for ES-DER standards

- **Task 1: Use Cases, EPRI Smart Inverter**
  - Define requirements for different scenarios

- **Task 2: IEEE 1547.4 for Island applications and IEEE 1547.6 for secondary networks**

- **Task 3: Unified interconnection method with multifunctional operational interface for range of storage and generation/storage.**
  - IEEE 1547.8
  - (a) Operational interface
  - (b) Storage without gen
  - (c) PV with storage
  - (d) Wind with storage
  - (e) PEV as storage

- **Task 4: DER Object Models and Mappings**
  - IEC 61850-7-420, -90-7: Expanded to include
    - Multifunctional ES-DER operational interface
    - Harmonized with CIM & MultiSpeak
    - Map to MMS, DNP3, web services, & SEP 2

- **Task 5: Test, Safe and Reliable Implementation**
  - UL 1741 SA,
  - NEC-NFPA70

### PAP 24: Microgrid Operational Interfaces

- **Task 0: Scoping Document**
  - Define microgrid standards needs

- **Task 1: Use Cases: Functional + Interactive EPRI DERMS**
  - Define requirements for different scenarios

- **Task 2: Microgrid Interconnection standard for grid-interaction**
  - IEEE 1547 Series

- **Task 3: Unified microgrid-EMS controller standard**
  - IEEE P2030.7

- **Task 4: Regulatory Framework**
  - a) State
  - b) Federal
  - c) NARUC

- **Task 5: Smart Microgrid Controller Information Models**
  - IEC 61850 Series: CIM, MultiSpeak

- **Task 6: Microgrid Controller and Interconnection Equipment Test**
  - Controller Test – IEEE P2030.8; Info exchange; Interconnection; Safety; System Impact

Primary Contributions by Al Hefner and NIST Associates
### Standards & NIST: ANSI C12.20-2015

- **Creates a 0.1 accuracy class** (±0.1%)
- **Includes harmonic waveform testing**
- ANSI C12/SC16 Committee chaired by NIST’s **Shannon Edwards**
- ANSI C12 chaired by NIST’s **Tom Nelson**

**Test #39:** 90 Degree phase fired waveform

**Test #41:** Peaked waveform
PC 118 Smart grid user interface

**Scope:** Standardization in the field of information exchange for demand response and in connecting demand side equipment and/or systems into the smart grid

- IEC TR 62939-1:2014 Smart grid user interface – Part 1: Interface overview and country perspectives
- IEC 62939-2 Smart grid user interface – Part 2: Architecture and requirements (CD in review)
- IEC 62939-3 Smart grid user interface – Part 3: Energy interoperation services (CD in review)
- IEC 62746-10-1 Systems interface between customer energy management system and the power management system – Part 10-1: Open Automated Demand Response (CDV ballot in progress)
- IEC 62746-10-3 Systems interface between customer energy management system and the power management system – Part 10-1: Adapting smart grid user interfaces to IEC CIM (CDV ballot in progress)

NIST involvement: Steven Bushby, David Holmberg
Standards & NIST Smart Grid Program

Information
- BACnet (ISO 16484-5)
- FSGIM (ISO 17800)
- Green Button (NAESB REQ.21)
- IEC PC118 (OpenADR)
- IEEE 1815.1-2016
- SAE J2836/3
- IEEE 21451

Device & Measurement
- ANSI C12.20-2015
- IEC/IEEE 60255
- IEC 60859
- IEEE 1613.1
- UL 1741
- IEEE C37.118
- IEEE C37.242

Operations
- IEEE 1547.1
- IEEE 1547.4
- IEEE 1547.8
- IEEE 2030.2
- IEEE 2030.5
- IEEE 2030.7
- IEEE 2030.8
- NEMA IPRM
- IEC 61850-7
- IEC 61850-9
- IEEE C37.238
EXPERIMENTAL FACILITIES
Experimental Facilities: Smart Grid Testbed

- Smart Grid Testbed Expansion expected to be completed this month (August 2017)
  - Followed by testing of the electrical power equipment and safety interlock system prior to commissioning.
  - Multi-OU safety coordination group reviewing all hazard reviews, safety incidents and concerns
  - Guidance document, operational processes, and safety manual are complete or near final draft form.
  - Hazard Reviews will begin after handoff from Plant
- FY18:
  - Microgrid Power to be extended into the Great Room
  - Hazard Reviews completed for A21 Smart Storage
  - Testbed Network operational across all testbed rooms
  - Develop testbed user management tool
  - Engage stakeholders / internal users to revise testbed vision
Experimental Facilities: Testbed commissioning

Electric Service: 480 V, 600 A Panel in Attic.

Building Electric Service
Bldg. 220 Attic
Lab Energy Sources
Bldg. 220, Rm A27, A21
Safety Interlocked
Shunt Trip Breakers:
Bldg. 220, Rm A27, A21

Experimental Power –
Grid/Source Emulators
Bldg. 220, Rm A27, A21

Microgrid/DER Power –
Interconnection Equip.
Under Test
Bldg. 220, Rm A27, A21

Smart Grid Loads, Sensors, IEDs,
Networks Under Test
Bldg. 220, Rm A13-19,

Key FY18 Plans

• Demonstrate conformance testing for smart inverter functions for 10 kW and 30 kW systems

• Acquire microgrid and DERMS controllers

• Demonstrate conformance test of advanced interactive microgrid controller functions

• Demonstrate interoperability testing and performance characterization of multiple DERs and loads
RESEARCH
Research: A bit of context

- 30 Researchers
- 9 Divisions
- 4 Laboratories

### Smart Grid Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
</tr>
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<tbody>
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<td>Cybersecurity for Smart Grid Systems (ITL)</td>
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<td>Quantifying Key Economic Issues in the Smart Grid (EL AEO)</td>
<td>O'Fallon</td>
</tr>
</tbody>
</table>

This is just the research linkages

Does not include coordination, testbed, or external collaborations
Research: Common Themes

- Monitoring and Control
- Cybersecurity
- Communications and Timing
- Operations and Economics

NOT YET
RESEARCH: CYBERSECURITY
How to think about cybersecurity
Characterizing cyber vulnerabilities by their physical impact

When sensors or sensor aggregators are attacked, the primary impact of the attack is on the state estimator. Inaccurate state estimates in turn may result in bad control decisions.
RESEARCH: COMMUNICATIONS
Varying QoS Requirements for Smart Grid Applications

- Right figure shows QoS requirements for a set of applications identified in the OpenSG Smart Grid Requirements matrix, as an outcome of Smart Grid Interoperability Panel (SGIP) Priority Action Plan 2 (PAP02).
- This calls for the study of future network technologies and architectures (5G, etc.) to support smart grid and other CPS.

**Use Cases**

- **CMSG**: Customer Information / Messaging
- **DDCS**: Dispatch Distributed Customer Storage
- **DRDLC**: Demand Response-Direct Load Control
- **DSDRC**: Demand Response-Centralized Control
- **FCIR**: Fault Clear, Isolation, and Reconfigure
- **FDAMC**: Field Distribution Automation Maintenance-Centralized Control
- **FPU**: Firmware/Program Update
- **IDCS**: Islanded Distributed Customer Storage
- **ME**: Meter Events
- **MR**: Meter Reading
- **ORM**: Outage Restoration Management
- **PHEV**: Plug-in Hybrid Electric Vehicle
- **PNA**: Premise Network Administration
- **PP**: Prepay Price
- **SS**: Service Switch
- **VVC**: Volt/VAR-Centralized Control

Figure: Major Smart Grid Use Cases, Categorized by Latency and Reliability Requirements

Combined Grid/Communication with Multiple Test Configurations

Hardware-in-the-loop experiments

- Grid Simulation Model
  - GPS-Synchronized Digital Waveforms
- Virtual PMUs
- PMU Streaming
- Data Files
- DAC+ AMP.
- PMU Devices
- GPS Antenna

Real Grid Network
- Electric Waveforms
- PMU Devices
- GPS Antenna

New approaches to observability

Application Layer Interface

- Application Layer: PMU Data, IEEE C37.118.11
- Transport Layer: UDP/IP
- Network Layer (Wireless)
  - Centralized: (Cellular) Networks
  - Distributed
- LLC/MAC, e.g., CSMA: IEEE 802.11, 3GPP-LTE
- PHY
RESEARCH: TIME
System physics drives timing requirements

Time of arrival accuracy determines location precision and accuracy

Requirement of < 1 µs synchronization

Time error manifests as measurement error

High frequency transients require fast sampling

Changing dynamics require lower latencies

Data source: Matthew Boyd, NIST

Timing Priorities (at NIST)

Improving integrity assurance in timing for power systems

Testing and certification
- Device conformity
- End-to-end system interoperability
- Quantifiable test methods
- Interoperability events

Monitoring and anomaly detection
- Real-time monitoring against traceable reference source
- Stochastic characterization of normal behavior

Applications driven requirements
- Research system dynamics
- Parameterize performance metrics and requirements
- Explicit time specification

Alternative sources
- Terrestrial radio (eLORAN, WWVB)
- Network (PTP, NTP)
- Ensembling multiple sources
RESEARCH:
WIDE AREA MONITORING AND CONTROL
• Models are relied upon throughout the power system.
  • We compare measurements of “actual values” against model predictions to help validate the model
    – But how actual are the “actual values?”
      • And how bad can they be before there is a problem?

• NERC requires models to be validated
  – Many policies, reports and papers have been published on the topic.
• What is the impact of synchronized measurement error on model validation?
Uncertainty is a dominant challenge

- **Grid is highly distributed and complex**
  - Increasing diversity of device, resource, and control

- **Uncertainty is growing**
  - Growing numbers and increasing dynamics of variables lessen the likelihood of well-behaved, predictable system
  - Legacy models and tools incapable of addressing the growing uncertainty

- **Progress needed across multiple dimensions**
  - New grid physics
  - Networked measurements
  - Diversified applications
  - Expanding customer-base
Two years ago, NASPI formed the PMU Applications Requirements Task Force – NASPI-wide, about 40 members

NASPI, NIST, and PNNL collaborated on a white paper which is published by NASPI today. Provides guidelines and terminology for assessing application needs

Work is in progress at NIST, collaborating with PNNL, WSU, GE, BPA and other vendors, academics, and utilities to create an open source composable application testing framework.
There are several applications being considered for PMUs in the distribution circuit. Each of these applications use a different representation of uncertainty.

<table>
<thead>
<tr>
<th>Dynamic State Estimation</th>
<th>Additive White Gaussian models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring and Protection</td>
<td>Confidence intervals</td>
</tr>
<tr>
<td>Fault Localization</td>
<td>Bayesian inference</td>
</tr>
<tr>
<td>Harmonic Estimation</td>
<td>Mixed Gaussian models</td>
</tr>
<tr>
<td>Load modeling</td>
<td>Markov models</td>
</tr>
<tr>
<td>Parameter estimation</td>
<td>Set theoretic models</td>
</tr>
<tr>
<td>Closed loop control of feeders</td>
<td>Stochastic optimization</td>
</tr>
</tbody>
</table>

Differentiating error vs. uncertainty and formally specifying uncertainty of sensor measurements and corresponding models will greatly aid in the ability of designers and operators to propagate uncertainty through multiple interacting components and to develop confidence in system level performance.
RESEARCH: BUILDING INTEGRATION WITH SMART GRID
Green Button Initiative

- Enables electronic consumer access to energy data and supports development of ecosystem (apps)
- Available to 100+ million consumers in the US and additional CANADA: 8 million+ consumers
- Result of collaboration among White House, NIST, DOE, state regulators, utilities, vendors, SGIP, and North American Energy Standards Board
- Trade Org: Green Button Alliance
Transactive Energy Challenge: Phase 1

Building up the TE community and TE model simulation foundations

Seven teams/workflows

Knowledge gained
Research: Common Themes

**GOAL:** Maximize the ability of grid systems to accommodate DER

- **Monitoring and Control:** Improve our understanding of distribution system dynamics, and enhance our ability to control and optimize the system.

- **Cybersecurity:** Enable ever-diversifying devices to securely interact, and facilitate reliable and resilient grid operations.

- **Communications and Timing:** Maximize system controllability while minimizing infrastructure and computational overhead.

- **Operations and Economics:** Quantify how changing economic context impacts technology applications and potential.
Enhance our ability to control distribution systems

- Commission equipment in testbed, to include:
  - Grid/load emulators
  - Smart inverter functions at 10kW (=> 30kW)
  - Configure and program example microgrid scenario using microgrid controller, rotating machine generator emulator, and loads

- Demonstrate conformance testing of microgrid controller using IEEE 2030.8
- Demonstrate interoperability testing of multiple DER’s and Loads
- Coordinate development of microgrid controller information model

Output: Microgrid Interoperability Testbed that provides capability to test conformity of power conditioning systems devices to standards, and to test interoperability of multiple devices in microgrid scenarios
Research: Monitoring and Control

Improve our understanding of distribution system dynamics

Can we evaluate the limits of distributed sensing with installed base?

In 2018 NIST will test smart meters with highly distorted waveforms to assess metering errors.

The results will help us understand the extent to which smart meters can be used as distributed voltage and current sensors

Is data exchange between sensors possible as intended?

In 2017 NIST constructed an interoperability test station, evaluated against IEC 61850-9-2 based Merging Units

In 2018 NIST will quantify measurement uncertainties and develop a software tool to analyze microgrid interoperability across sensors
Enable secure device interactions: Create architecture driven cybersecurity risk profiles

Characterize authentication and encryption performance for publish-and-subscribe networks (e.g., OpenFMB)
Facilitate reliable grid operations by using Physical dynamics as a metric for security tools (inf-TESLA)

The delayed system is asymptotically stable if there exists real symmetric positive-definite matrices $P = P^T > 0$, $Q = Q^T > 0$ satisfying the LMI:

$$
\begin{bmatrix}
PA_s + A_T^TP + Q & PA_v \\
A_T^TP & -Q
\end{bmatrix} < 0
$$
Increasing Interoperability

- **Certification Test Specification**
  - Plug-fests

- **Certification Test Harness**
  - Conformance Tests

- **Interoperability Tests**
  - Interop Test System
  - Deployment testing

- **PICS**

- **SSO Technical Specification**

- **Standards**

- **Source:** Bob Noseworthy, et. al Draft 1588 Power Profile Conformance Test Suite Specification. University of New Hampshire Interoperability Lab.

- **Collaborate with industry to accelerate the development of test programs for smart grid standards**
- **Support industry test programs through test methods development**
- **Participate in plug-fest and interoperability test events**
- **Build awareness and encourage adoption of test programs to enhance interoperability**
Minimize infrastructure for smart implementation of distributed applications by characterizing technologies and architectures for efficient future wireless networks.

Systematically investigate different techniques for energy resource management in 5G:
- **X-axis**: Mechanisms for control (centralized vs. distributed, User Equipment vs. base station control)
- **Y-axis**: Adaption based on network status
- **Z-axis**: Mechanisms for resource management with respect to time, frequency and spatial domains
Research: Operations and Economics

TE Challenge Phase 2:

- Model the same electric grid with the same scenario
- Implement different TE models
- Report results using common metrics
  
  Price, V/VAR, Actuations, ANSI C84.1 violations, total load, appliance load, …
Research: Operations and Economics

New study: The Economics of Interoperability in Smart Grid Operations

Average Price of Electricity by State and End Consumer Group

Sector with Lowest Unit Cost of Demand Response
### NIST Smart Grid Program – Current Budget

<table>
<thead>
<tr>
<th>Smart Grid Program</th>
<th>FY17 $(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experimental Facilities: Smart Grid Test Bed</strong></td>
<td>$2,469</td>
</tr>
<tr>
<td>Smart Grid System Testbed Facility (SL SGP) - Boynton</td>
<td></td>
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<tr>
<td>Power Conditioning Systems for Renewables, Storage, and Microgrids (PML) - Hefner</td>
<td></td>
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<tr>
<td><strong>National Coordination + Strategy</strong></td>
<td>$2,771</td>
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<tr>
<td>Smart Grid Secretariat (EL SGP) - Gopstein</td>
<td></td>
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<tr>
<td>Smart Electric Power Alliance (EL SGP) - Nguyen</td>
<td></td>
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<tr>
<td>Smart Grid Testing and Certification (EL SGP) - Nguyen</td>
<td></td>
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<tr>
<td><strong>Research Projects</strong></td>
<td>$3,295</td>
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<tr>
<td>Cybersecurity for Smart Grid Systems (ITL) - Hastings</td>
<td></td>
</tr>
<tr>
<td>Smart Grid Communication Networks (CTL) - Griffith</td>
<td></td>
</tr>
<tr>
<td>Smart Grid Communication Networks (ITL) - Gharavi</td>
<td></td>
</tr>
<tr>
<td>Precision Timing for Grid Systems (ITL) - Li-Baboud</td>
<td></td>
</tr>
<tr>
<td>Wide-area Monitoring and Control of Smart Grid (PML) - FitzPatrick</td>
<td></td>
</tr>
<tr>
<td>Electromagnetic Compatibility (CTL) - Ladbury</td>
<td></td>
</tr>
<tr>
<td>Building Integration with Smart Grid (EL) - (*not incl. $300k EIB) - Holmberg/Gopstein</td>
<td></td>
</tr>
<tr>
<td>Quantifying Key Economic Issues in the Smart Grid (EL AEO) - O'Fallon</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>$8,535</td>
</tr>
</tbody>
</table>
Smart Grid Interoperability and Building-to-Grid Integration

Steven T. Bushby
Group Leader, Engineering Laboratory
NIST Embedded Intelligence in Buildings Program
There is no Smart Grid without Smart Buildings!

- 72% of electricity is consumed in buildings (40% commercial, 32% residential)
- Increased building automation capabilities and building-scale renewable generation make building interactions increasingly important to the grid
- As the nation migrates to electric vehicles, they will be plugged in to buildings

Buildings will no longer be a dumb load at the end of the wire. They will become an integral part of the grid.
Building Resources Potentially Available to the Grid

- Generation
- Electrical and thermal storage
- DR to reduce peaks
- Fast DR for some ancillary services
- Load forecasts to improve planning

The scale in homes is much smaller but there are many of them.
Facility Smart Grid Information Model – An Example of NIST’s Impact

- Examples of NIST capabilities relevant to this effort are:
  - Technical leadership
  - Ability to bring together diverse stakeholders and standards development organizations (SDOs)
  - Leverage leadership positions in national and international standards organizations
  - Ability to coordinate with technical experts in the private sector and other federal agencies
Today’s Automation and Control Technology

• Industrial – Ubiquitous, mature, capable but generally not configured to support grid needs

• Large Commercial –
  – Installed base slow to change (20 year life)
  – BACnet the dominant technology being installed today
  – Strong trend towards greater system integration and more sophisticated control strategies

• Small Commercial and Residential
  – Limited automation and control – mostly thermostats
The Problems

- Control technology and maturity varies by building sector
- Utilities and energy service providers want to interact with all building types in the same way
- Different SDOs have jurisdiction over different building sectors (AHAM, ASHRAE, ISA, NEMA)
- We need solutions that are accepted internationally
- Standards for buildings need to fit within the context of other smart grid standards and activities.
- Regulators want to enable innovation while ensuring resilience and reliability
The Solution

Develop an information model standard that is applicable across the building space and provides a common evolutionary path for automation and control technologies in each space

- Create a multi-SDO collaboration
- Build a balanced team of experts that represent the various stakeholders
  - Commercial/Institutional/Industrial Producer
  - Appliance, Residential Automation, and Consumer Electronics Producer
  - Utility
  - Consumers – Residential, Commercial, and Industrial
  - General Interest
- Conduct domestic outreach during development to get early feedback
- Conduct international outreach to build support for adoption of the results as an international standard
- Leverage electronic meetings to increase participation and accelerate progress
PURPOSE: The purpose of this standard is to define an abstract, object-oriented information model to enable appliances and control systems in homes, buildings, and industrial facilities to manage electrical loads and generation sources in response to communication with a “smart” electrical grid and to communicate information about those electrical loads to utility and other electrical service providers.
The model will support a wide range of energy management applications and electrical service provider interactions including:

(a) on-site generation,
(b) demand response,
(c) electrical storage,
(d) peak demand management,
(e) forward power usage estimation,
(f) load shedding capability estimation,
(g) end load monitoring (sub metering),
(h) power quality of service monitoring,
(i) utilization of historical energy consumption data, and
(j) direct load control.
Imagine modeling all devices behind the ESI as either an energy manager, energy meter, energy generator, or energy load.

Examples might be:

- EMS = Energy Manager
- Smart Appliance = Energy Manager + Load
- Battery = Generator + Load
- Premise sub-meter = Meter
Composition of Devices from Components

- Customer Energy Management System (CEMS)
- Ice Storage
- Battery Storage
- Smart Grid
- Solar PV
- Sub Meter
- PHEVs
- Virtual Load
- Lighting
- Cameras
- AHUs
- Chillers
- Lighting
- Smart Grid
- Meter
- Servers
- Fans
- Thermostat
FSGIM Overview

Grid-side protocols and services.

- Weather Data
- Real-Time Energy Pricing
- Demand Response
- Energy Usage Info
- ...

FSGIM Device

- Energy Manager
- Load
- Meter
- Generator

Facility-side protocols and services.

- HVAC
- Lighting
- Security
- Facility Management
- Industrial Automation
- ...

NIST smart grid program
Early Impact of the FSGIM

- Compatible with Green Button, OpenADR and weather information services
- Provides standard aggregations that will work in a multi-vendor environment
- Can represent load curves for predicting energy and power consumption or selecting control points

Control technology standards groups are beginning to develop technology specific implementations of the FSGIM
Securing Grid Edge Devices

Nelson Hastings
Group Leader, Cybersecurity and Privacy Applications Group
Applied Cybersecurity Division
Information Technology Laboratory
Security of Grid Edge Devices

• Grid edge devices include Smart Meters, Inverters, Thermostats, HVAC systems, ...
• Securing these devices is critical to scaling control systems that may leverage grid edge devices.
• The NISTIR 7628 provides Guidelines for Smart Grid Cyber Security.
• Ideally we would like a strategy to decompose these system level guidelines to device specifications.
Cybersecurity Efforts

• Profiling Performance of Grid Edge Devices

• Secure Publish-Subscribe Communications
Profiling Performance of Grid Edge Devices

• We are currently developing technology to profile the performance impact of security solutions on grid edge devices.
• The eventual goal is to balance cybersecurity tools across a DER architecture, minimizing system level risk exposure.
• Diversity in design, legacy and communication protocols pose a challenge – requiring continuing engagement with device manufacturers.
Grid Edge Device Test Infrastructure

Draft NIST SP 800-193 Platform Firmware Resiliency Guidelines
Classes of Test Devices

- Smart Meters
- Inverters
- EV Charging Stations
- Thermostats
Performance statistical profiling of applications
- Contribution of different security routines in App/OS space to execution cost
- Profile various software events (instructions, cache misses, etc.)
Hardware/Firmware in the loop testing

- Contribution of different hardware/firmware security tools (crypto, MAC, Network)
- Profile various hardware events (clock cycles, network use, buffers, etc.)
- Use hardware probing and network monitoring to sample pub-sub protocols, hardware interrupts, etc.
Results Matrix

• We plan to construct a matrix of hardware platforms commonly used in smart grid devices with performance metrics of the encryption libraries that are enabled on them.
• The test will baseline performance of various devices by measuring the performance different encryption algorithms in bytes/second and bytes/cycle.
• This will catalog expected performance impacts by enabling security features on a wide swath of smart grid devices.
Secure Publish-Subscribe Communications

- Review the NAESB RMQ.26 standard for implementing Open Field Message Bus (OpenFMB)
- Actively participating in the SEPA OpenFMB Cybersecurity Task Force (CTF)
- Perform a security review of NAESB RMQ.26 and corresponding OpenFMB CTF output
- Design and build a proof of concept implementation of OpenFMB
Collaboration

• National Renewable Energy Lab (NREL)
• OpenFMB CTF Members:
  – Avista
  – Coergon
  – Duke Energy
  – Electric Power Research Institute
  – FREEDM Systems
  – General Electric Company
  – Green Energy Corp
  – Itron, Inc.
  – Landis+Gyr – Toshiba
  – OMNETRIC Corp.
  – Real-Time Innovations, Inc.
  – Red Hat
  – Xanthus Consulting International
  – Xcel Energy Inc.
Timeline

• Profiling Performance of Grid Edge Devices
  – Q4 FY17 – Design test plan
  – Q1 FY18 – Complete design and procure equipment as needed
  – Q2 FY18 – Conduct test and collect data
  – Q3-Q4 FY18 – Produce data set from results
  – Q3-Q4 FY18 – Create document recording test architecture, results, and implications

• Secure Publish-Subscribe Communications
  – Ongoing – SEPA OpenFMB CTF participation
  – Q1-Q4 FY18 – Perform security review of NAESB RMQ.26
  – Q2-Q4 FY18 – Design and implement PoC implementation of OpenFMB
Mitigating the impact of stochasticity in future power systems

Dhananjay (DJ) Anand

Federal Advisory Committee Meeting
08/17/2017
Uncertainty and Variability in Distribution Circuits

Epistemic Uncertainty
- Uncertainty in circuit parameters
- Lack of observability on circuit buses
- Limited measurement of terminal loads
- Limited modeling of generation sources

Aleatory Variability
- Stochastic generation sources
- Aggregate statistical behavior of flexible loads
- Exogenous circuit parameters
- Quasi-equilibria in a system with non-convex objectives
Uncertainty and Variability in Distribution Circuits

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- Quasi-equilibria in a system with non-convex objectives

Parameter Sensitivity: $$H(X) := \frac{\partial h(X)}{\partial X}$$

Unobservable dynamics: $$||\mathcal{R}(H(X))||$$

$$S = \sum \lambda_i x_i$$

$$\mathbb{E}(Q|X) = \sum_{Q \in S} Q \cdot P(Q|X) ;$$

$$P(Q|X) = \frac{P(X|Q)P(Q)}{P(X)}$$
Advancing to measurement and validation of ‘systems’

\[
\begin{align*}
\hat{Q}_{12} & = V_2 V_3 B_{23} \cos(\theta_2 - \theta_3) + V_2 V_6 B_{26} \cos(\theta_2 - \theta_6) \\
\hat{Q}_{26} & = V_2 V_6 B_{26} \cos(\theta_2 - \theta_6)
\end{align*}
\]
Challenges in factoring systemic uncertainty

- Dynamics are non-linear, hybrid and have multiple degrees of freedom.
- Communication models include stochastic loss and delay parameters.
- Control algorithms tend to use reduced order approximations resulting in state dependent uncertainty.

- Computational burden would be prohibitive for traditional Monte Carlo methods.
- Finite order stochastic formulations are needed for Sensitivity Analysis.
- Partial derivatives of system outputs (or parameters) with respect to the uncertain quantities tend to be numerically ill-posed.
- Bounds on the validity of model approximations form high order polytopes.
- Stochastic excitation of continuous dynamics interact with switched or delayed systems.

\[
\begin{bmatrix}
\hat{Q}_{12} \\
\hat{Q}_{26}
\end{bmatrix} = 
\begin{bmatrix}
V_2V_3B_{23} \cos(\theta_2 - \theta_3) + V_2V_6B_{26} \cos(\theta_2 - \theta_6) \\
V_2V_6B_{26} \cos(\theta_2 - \theta_6)
\end{bmatrix} + 
\begin{bmatrix}
\varepsilon_1(V, I, \phi, \theta, \ldots) \\
\varepsilon_2(V, I, \phi, \theta, \ldots)
\end{bmatrix} + 
\begin{bmatrix}
\mathbb{E}(Q_{12}|X) \\
\mathbb{E}(Q_{26}|X)
\end{bmatrix}
\]
We plan to adopt three concurrent strategies

1. Minimize uncertainty within each component – leveraging current efforts.

2. Characterize the stochastic properties of the residual uncertainty to improve forecasts and model based estimates.

3. Propagate the uncertainty through interacting components while retaining analytical capabilities.
Improved measurements

Epistemic Uncertainty

- Uncertainty in circuit parameters
  - NIST programmable Josephson voltage standard
  - NIST quantum Hall resistance standard
  - Maxwell-Wien bridge inductance standards
  - Calculable capacitor reference standard
  - Atomic standards for frequency

- Lack of observability on circuit buses
  - Synchrometrology

- Limited measurement of terminal loads
  - Improved energy/power metrology at grid edge

- Limited modeling of generation sources
  - Quantum characterization of solar PV cells
  - Electrical Performance of PV modules
NIST Efforts in physics based modeling and validation

Better modeling

Aleatory Variability

- Stochastic generation sources (PV)
  - Models of PV modules
  - NOAA sourced irradiance spectra

- Aggregate statistical behavior of flexible loads
  - Occupant and Latent Load Simulator (NZERTF)

- Exogenous circuit parameters
  - Reference models for transducers
  - Transformer loss models
  - Models for solid state switching devices

- Quasi-equilibria in a system with non-convex objectives
  - NIST solver for 2D elliptic PDEs on distributed memory parallel computers and multicore computers (PHAML)
We plan to adopt three concurrent strategies

1. Minimize uncertainty within each component – leveraging current efforts.
2. Characterize the stochastic properties of the residual uncertainty to improve forecasts and model based estimates.
3. Propagate the uncertainty through interacting components while retaining analytical capabilities.
Example: Voltage regulation with high PV penetration
Improve analytical approximations for $w(k)$

Track, predict and linearize insolation estimates over $10^1 - 10^3$ second horizon.
Improve analytical approximations for $w(k)$ (linearization)
Disturbance characterization is non-trivial

Solar Irradiance and Cell Temperature (input parameters)

PV Array and impedance circuitry

MPP Tracking

DC-bus Boost converter and Startup charging

3-phase Inverter Bridge

3-phase load

Linearized stochastic excitation \([w_k]\)

Controlled variables \([Q_s, P_s]\)
We plan to adopt three concurrent strategies

1. Minimize uncertainty within each component – leveraging current efforts.

2. Characterize the stochastic properties of the residual uncertainty to improve forecasts and model based estimates.

3. Propagate the uncertainty through interacting components while retaining analytical capabilities.
Uncertainty propagation through physics and time

A reduced order stochastic formulation will allow us to propagate (dynamic evolution of a projection) in order to minimize uncertainty of the **current as well as the future state**.

An existing method to represent the coupling between multiple Stochastic Differential Equations is the FPK equation.

A PDE that describes the **time evolution of the probability density function** of a trajectory under the influence of random forces.

**Electrical power systems present some unique pitfalls!**
Our proposed finite order stochastic formulation

Gaussian mixture models bounded by convex hulls.

The approach is amenable to a-posteriori adaptation in response to measurements.

Able to leverage both the FPK formulation as well as the geometric propagation of convex hulls through switched or hybrid dynamical systems.

\[ \varepsilon(V, I, \phi, \theta, \cdots) \]

\[ \mathbb{E}(Q|Z_1^{\infty}) \]

\[ \mathbb{E}(Q|Z_2^{\infty}) \]
Validation using NIST campus’ distribution circuit
Thank you

1. Minimize uncertainty within each component.

2. Characterize the stochastic properties of the residual uncertainty to improve forecasts and model based estimates.

3. Propagate the uncertainty through interacting components while retaining analytical capabilities.
NIST Smart Grid Advisory Committee SEPA Update - 2017

Sharon Allan
Chief Innovation Officer
August 15, 2017
History of SGIP >> SEPA
The Timeline . . .

- Sept 2009: NIST SG Interoperability Framework 1.0
- July 2011: First 6 Entries In the CoS
- Dec 2012: SGIP 2.0, Inc
- Sept 2014: NIST SG Interoperability Framework 3.0
- March 2015: BoD reduced from 22 to 12
- Feb 2017: SGIP closes 6 PAPs
- April 2017: SGIP merges with SEPA
- 81 Entries in CoS

2017 Priority Action Plan Closures:
- PAP-15: Harmonized Power Line Carrier
- PAP-17: Facility Smart Grid Information Standard
- PAP-20: Green Button ESPI Evolution
- PAP-21: Weather Information
- PAP-23: IEC 61850 Testing Profiles
- PAP-26: Distributed Intelligence
3 Priority Action Plan Closures

SGIP WHITE PAPERS PUBLISHED

New Committees/Subgroups Formed
• Technical Advisory Council (TAC)
• Catalog of Test Programs (CoTP)
• OpenFMB Management Services Task Force

The Catalog of Standards Visualization Tool
• The Catalog of Standards Visualization Tool went live in February 2017.
• 81 Standard in CoS

Webinars
• Cyber-Physical Resiliency Webinar
• Economic Value of the Integration of Consumption Preferences in Electric System Planning Webinar
• Evaluation of the Electromagnetic Phenomena Issues on Smart Grid Reliability Webinar
• H/B/I2G DEWG Smart Grid System Security with Broadcast Communications
• Orange Button Webinar -
• Orange Button Year Two Update Webinar
• Smart Grid Cybersecurity Committee Webinar: A Comparison of How Key Cybersecurity Standards Affect Smart Grid

2017 Educational Webinars

Webinars Held
7

Total Attendees
560+

Total Registrants
1177

Webinar Participant Geographic Regions
Algeria, Australia, Bangladesh, Brazil, Canada, China, Colombia, Ecuador, France, India, Japan, Korea (South), Malaysia, Mexico, New Zealand, Portugal, Romania, Singapore, South Africa, Spain, Turkey, United Kingdom, and United States

25 Countries

Working Groups
350+ Meetings Held
1650+ Participants
285+ Hours of Meeting & Collaboration
## Priority Action Plan Status

### 3 PAPs Remain Open

<table>
<thead>
<tr>
<th>PAP Number</th>
<th>PAP Name</th>
<th>PAP Status</th>
<th>PAP Next Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>EV Fueling Submetering Requirements</td>
<td>OPEN</td>
<td>1) Awaiting NEMA EVSE specification publication (estimated within two months); 2) Planning to publish EVSE application whitepaper</td>
</tr>
<tr>
<td>24</td>
<td>Microgrid Operational Interfaces</td>
<td>OPEN</td>
<td>Ongoing work coordinated with IEEE SA. Awaiting report of results of balloting for approval of IEEE 2030.7 and 2030.8. Also developing white paper on Technical Implications of Regulatory Environment for Microgrids.</td>
</tr>
<tr>
<td>25</td>
<td>Orange Button: Harmonized Financial Data</td>
<td>OPEN</td>
<td>PAP 25 scope included in Orange Button DOE project. This PAP will close when Orange Button is complete and closed.</td>
</tr>
</tbody>
</table>

### 24 PAPs Have Been Closed

![Table of 24 closed PAPs](image-url)
CoS is available via the Web

10+ new candidate standards have been suggested, SIFs not submitted yet
The Journey

- SEPA Staff is a total of 48 with SGIP
- Combined Revenues near $10M

- Over the course of the last 3 years we have been keeping Revenue flat by diversifying sources as NIST funding decreased
- SEPA is a step change in Revenue

SEPA Staff is a total of 48 with SGIP
Combined Revenues near $10M
On April 1, 2017, SGIP merged with the Smart Electric Power Alliance (SEPA)

**Mission**

To facilitate the electric power sector’s smart transition to a clean energy future through education, research, standards, and collaboration.

**Membership**

Total Members = 1032

- Utility: 574
- Govt, ass, nonprofits: 155
- Corporates: 303
The SEPA Board

Bruce Edelston, VP of Energy Policy, Southern Company
Caroline Choi, SVP Regulatory Affairs, Southern Calif Edison
Jill Anderson, EVP, NY Power Authority
Jim Albert, SVP, HECO
Matt Handel, VP of DG and Storage, NextEra Energy
Jim Rogers, Former Chairman of Duke
Raiford Smith, VP Emerging Technologies, Entergy
Joe Hoagland, VP Stakeholder Engagement, TVA
Paul Lau, Chief Strategy Officer, SMUD
Rob Caldwell, President Renewables & Storage, Duke
David Forfia, Dir IT Transformation, ERCOT
John Hewa, VP Corp Services, Rappahannock
Mark Nielson, VP Service, Delaware Electric Coop
Karen Butterfield, COO, STEM
Ron Binz, Binz Consulting
Seth Frader-Thompson, CEO, Energyhub
Steve Malnight, SVP Strategy & Policy, PG&E
Tom Starrs, VP, Sunpower

2017 Ex-Officios and members of the TAC (Tech Adv Council)
Andres Carvallo, CMG
David Wollman, NIST
Robby Simposn, GE
Nick Wagner, Iowa PUB
Michael Bates – Intel
Aaron Snyder – Enernex
Bill Ash – IEEE
Tony Thomas - NRECA
Grid Evolution Summit
July 2017

The community that's changing the electric power industry...

50+ Utilities

20+ State Regulatory Bodies

... and the education that's driving smart electricity forward

70+ Speakers & Thought Leaders

350 Attendees

THE MOST IMPORTANT ELECTRIC INDUSTRY TOPICS:

- Grid innovation
- Consumer engagement
- Information technology
- Rates and regulations
- Asset deployment
- Utility business models
- Retail & wholesale market design

Grid Evolution Summit
A National Town Meeting

Speakers Included:
- Avi Gopstein
- Cuong Nguyen
- Suzanne Lightman
- Nelson Hastings
- Tim Polk
- David Holmberg
- Dr. Greer

✓ 11 Working Group & Committee Meetings
✓ One Meet & Greet Technical Working Group Networking Breakfast
SEPA’s focus for 2017 is to complete the integration

- Integrate Web sites
- Integrate Accounting and Time Tracking
- Integrate Events ✔
- Integrate Working Groups
- Launch the TAC ✔
- Continue to support PAPs/CoS
- Expand reach of ’51st State’
- Continue to execute on existing programs ✔

SEPA appreciates the opportunity to work with NIST and looks forward to continuing our efforts together
Interoperability Framework Discussion

Avi Gopstein
Smart Grid Program Manager
Smart Grid and Cyber-Physical Systems Program Office
National Institute of Standards and Technology
U.S. Department of Commerce

August 17, 2017
NIST has “primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems…”
NIST Smart Grid Interoperability Framework

- Ongoing effort to “coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of Smart Grid devices and systems.”

- Includes smart grid conceptual reference model and conceptual architectural framework.
Interoperability Frameworks to date

NIST Special Publication 1108

NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0

Office of the National Coordinator for Smart Grid Interoperability

NIST Special Publication 1108R2

NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0

Office of the National Coordinator for Smart Grid Interoperability, Engineering Laboratory in collaboration with Physical Measurement Laboratory and Information Technology Laboratory

NIST Special Publication 1108r3

NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0

Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory in collaboration with Quantum Measurement Division, Semiconductor and Dimensional Metrology Division, and Electromagnetics Division, Physical Measurement Laboratory and Information Technology Laboratory

This publication is available free of charge from http://dx.doi.org/10.6028/NIST.SP.1108r3

http://dx.doi.org/10.6028/NIST.SP.1108r3
Interoperability Framework V1

Identified 25 standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>Application</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANI/IEEE C37.118.1000</td>
<td>Performance and safety type tests for revenue meters.</td>
<td>Promotes and optical interface for measurement devices.</td>
</tr>
<tr>
<td>IEC 61850-6 &amp; IEC 61850-50</td>
<td>BACnet defines an information model and services for building system communications of a consumer's site.</td>
<td>BACnet incorporates a range of networking technologies to provide scalability from very small systems to building systems that span whole campus networks.</td>
</tr>
<tr>
<td>IEC 61968-10</td>
<td>Open, multi-source standards.</td>
<td>Open, multi-source standards.</td>
</tr>
</tbody>
</table>

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NIST Special Publication 1108

NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0

Office of the National Coordinator for Smart Grid Interoperability

2010

NIST Smart Grid Framework 1.0 January 2010

Exploded network information exchange

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National Institute of Standards and Technology • U.S. Department of Commerce

Interoperability Framework V1

2010

NIST smart grid program
## Smart Grid Conceptual Model (2014)

### Roles/Services in the Domain

<table>
<thead>
<tr>
<th>Domain</th>
<th>Roles/Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Customer</td>
<td>The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: residential, commercial, and industrial.</td>
</tr>
<tr>
<td>2 Markets</td>
<td>The operators and participants in electricity markets.</td>
</tr>
<tr>
<td>3 Service Provider</td>
<td>The organizations providing services to electrical customers and to utilities.</td>
</tr>
<tr>
<td>4 Operations</td>
<td>The managers of the movement of electricity.</td>
</tr>
<tr>
<td>5 Generation</td>
<td>The generators of electricity. May also store energy for later distribution. This domain includes traditional generation sources (traditionally referred to as generation) and distributed energy resources (DER). At a logical level, “generation” includes coal, nuclear, and large-scale hydro generation usually attached to transmission. DER (at a logical level) is associated with customer- and distribution-domain-provided generation and storage, and with service-provider-aggregated energy resources.</td>
</tr>
<tr>
<td>6 Transmission</td>
<td>The carriers of bulk electricity over long distances. May also store and generate electricity.</td>
</tr>
<tr>
<td>7 Distribution</td>
<td>The distributors of electricity to and from customers. May also store and generate electricity.</td>
</tr>
</tbody>
</table>
Smart Grid Conceptual Model (2014)

SGAM Layers & Planes

- Conceptual
- Logical
- Physical
- Implementation

NIST smart grid program
Logical model of legacy systems mapped onto conceptual domains for smart grid information networks.
Questions to be addressed

- New domains?
- New interactions?
- New scales?
- Expanded mappings?
- New roles?
- Updated economics?
Future Activity (2018)

- NIST Smart Grid Interoperability Framework V4
- Number of viable Architectures expanding
  - Architecture is the integrated representation of possibility
  - No single model is adequate
- Significant impacts on:
  - Operations
  - Economics
  - Cybersecurity
  - Testing & Certification
- Current research
- Stakeholder engagement, feedback, and collaboration