Integrated Smart Grid Performance Testing

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i-PCGRID
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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...”
An integrated Approach to Smart Grid Testing

• Performance + interoperability
• Multidisciplinary – combines expertise of different NIST projects and laboratories to work together on multiple aspects of Smart Grid R&D
  – high-power inverters and power conditioning systems
  – microgrid operational interfaces
  – PMUs, smart sensors
  – cybersecurity
  – advanced networks
  – smart meters
NIST Smart Grid Testbed

Microgrid Interoperability Testbed

- Utility Network Emulator & DMS
- Oscilloscope and Network Analyzer
- Virtual Instrument Computer with Network and IEEE 488 Bus

Regenerative AC Grid Emulator
- 120 kW
- (phase, harmonics, transient faults, ...)

Grid, Backup Gen, or CHP Emulators
- 3 x 12 kW
- (phase, harmonics, transient faults, ...)

AC/DC Load Emulators
- 3 x 4.5 kW, 500 V
- (nonlinear, motor, reactive, rectifier, ...)

Regenerative DC Emulators
- PV, Bat, DC Server
- 3 x 12 kW 600 V
- + 3 x 12 kW 120 V

- SCADA
- LAN
- Probes
- EMCEM
- Power wires
- Other Smart Grid Generators, Storage, Loads

- Storage EMS
- EVSE or CES
- Battery Storage System Under Test

- Power Electronics, Relays, Sensors, Data Acquisition
- Microgrid Controller, Interconnection, PCS Under Test

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NIST Smart Grid Testbed

- SGIP Smart Grid Interoperability
- NIST Measurement Science
- DOE/DOD Labs, Test & Certification
- ESI, EMS, Microgrid & Storage functions

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**Other Smart Grid Generators, Storage, Loads**

- **SCADA**
- **Probes**
- **Power, Data, Meter options**
- **Storage EMS**
  - EVSE or CES
  - Battery Storage System Under Test
  - Power Electronics, Relays, Sensors, Data Acquisition

- **Microgrid Controller, Interconnection, PCS Under Test**

- **Utility Network Emulator & DMS**

- **IEEE 488**

- **Power wires**

- **LAN**

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NIST Measurement Science
DOE/DOD Labs, Test & Certification
ESI, EMS, Microgrid & Storage functions
IT Networks, Cyber Security, EMC, Sensors & Smart Meters
Power Electronic Interconnection Equipment
Grid-Interactive Microgrid, DER & Smart Appliances

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Microgrid Controller, ESI, EMS
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Grid-Interactive Microgrid, DER & Smart Appliances

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Virtual Instrument Computer with Network and IEEE 488 Bus

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

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

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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 models
  — Networked measurements
  — Diversified applications
  — Expanding customer base
Uncertainty representation in sensor standards

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>
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<tr>
<td>Monitoring and Protection</td>
<td>Confidence intervals</td>
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<td>Fault Localization</td>
<td>Bayesian inference</td>
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<td>Harmonic Estimation</td>
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<td>Load modeling</td>
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<td>Parameter estimation</td>
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<td>Closed loop control of feeders</td>
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PMU standards currently specify the error budget for the sensor but there is no explicit measure of uncertainty. 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.
Characterizing cyber vulnerabilities by 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.
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

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

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

• Synchrometrology is the scientific study of time-synchronized measurement.

• The NIST Synchrometrology Lab supports U.S. competitiveness and economic security through research and standards development in the field of time synchronized measurements in electric power generation, transmission, and distribution.
  —Co-funded by Departments of Commerce and Energy.

• Ongoing Projects:
  —Reducing measurement uncertainty in preparation for future requirements.
  —Collaborate in the assessment of the impact of errors in synchronized measurement on power system applications.
  —Collaborate in development of voluntary consensus standards and guides:
    • IEEE Standards Association
    • International Electrotechnical Commission.
  —Collaborate in the development of conformity assessment methods.
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.
Model Validation

• 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?
Alternatives to GPS for wide area time distribution

• GPS is known to be vulnerable to unintentional or intentional interference.

• If time sync becomes mission critical it must have redundant and differently routed sources.
Conformance and Interoperability Testing

- 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

NIST supports PMU conformity assessment by establishing traceability for IEEE ICAP Conformity Assessment Program.
Thank you!
NBS, NIST, and the development of the electric power industry
HV Research and Testing