NIST Framework for Smart Grid Interoperability Standards - Overview of PMU Performance Testing

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Outline

• **NBS, NIST, and the development of the electric power industry**
• NIST Framework and Roadmap for Smart Grid Interoperability Standards
• Smart Grid Interoperability Panel
• NIST Smart Grid Testbed
• Synchrometrology Laboratory
• Smart Grid sensors
NBS, NIST, and the development of the electric power industry
Major Northeast Blackout – August, 2003

Joint U.S. Canada task force identifies lack of observability as a major cause of this extensive blackout.

- Identifies Phasor Measurement Units (PMUs) as the best way to solve the problem.
NIST Synchrometrology Laboratory

• Established to provide state-of-the-art standards and performance testing facility for time synchronized power grid instrumentation – focus on PMUs
• Combine NIST Capabilities in Time Metrology and in Waveform Metrology
• Provide Assistance to Manufacturers and Utilities on Design and Use of PMUs and PMU Calibrators
• Created in 2006 – DoC/DoE funding
The NIST Role

Energy Independence and Security Act (EISA) of 2007
Title XIII, Section 1305.
Smart Grid Interoperability Framework

“In cooperation with the DoE, NEMA, IEEE, GWAC, and other stakeholders, 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…”
Plan: NIST Three Phase Plan to work with industry to accelerate standards

PHASE 1
Identify an initial set of existing consensus standards and develop a roadmap to fill gaps

Summer 2009 Workshops
Smart Grid Interoperability Panel Established Nov 2009
NIST Smart Grid Interoperability Framework 1.0 Released Jan 2010

PHASE 2
Establish Smart Grid Interoperability Panel (SGIP) public-private forum with governance for ongoing efforts

SGIP 2.0 Released Jan 2010
NIST Framework 2.0 Released Feb 2012

PHASE 3
Testing and Certification Framework
NIST Framework 3.0

2009 2010 2011 2012 2013
Smart Grid Interoperability Standards Coordination

NIST Smart Grid Framework document
- Release 3 (public comment Apr 2014)
- 2 (Feb 2012) and Release 1 (Jan 2010)
- Smart Grid vision & architectural reference model
- Identifies 100+ key standards; cybersecurity guidelines, testing and certification framework
- Provided a foundation for IEC, IEEE, ITU, and other national and regional standardization efforts

NIST Smart Grid Interoperability Panel (SGIP)
- Governing Board and committees, priority action plans
- Coordination of standards development by SDOs
- New SGIP 2.0, Inc. legal entity established, over 170 members
Problem: NIST/industry do not have an interactive platform to research smart grid (SG) technologies and measurement science, and demonstrate solutions to a full range of SG interoperability issues.

Solution: Develop a fully integrated SG measurements/validation testbed, with emphasis on microgrids.

Vital Role: Addresses national priority of SG interoperability, stds traceability, dissemination of data.

Attributes: Open-architecture, physics-based, scalable, renders fully characterized and validated model for residential and commercial/industrial microgrids.

Logistics: Ten contiguous laboratories. There are ~ 15 NIST personnel already supported by the Smart Grid & Cyber-Physical Systems Program Office.

FY13 Plan: (a) Renovate first suite of labs including upgraded electrical service, EMI shielding; (b) procure grid emulator, program loads, and instrumentation for power conditioning lab.

FY14: (a) Bring labs for cybersecurity, power conditioning, synchrophasors/sensors online; (b) renovate additional suite of labs; A013-A021.

FY15: (a) Bring labs for precision timing, power metering, modeling/evaluation of comm sys, sensor interface reliability, and storage metrology online
Under renovation

Future expansion

Note: Precision timing lab (PI Ya-Shian Li-Baboud) will remain in separate building with fiber optic connection to other labs.
NIST SynchroMetrology Laboratory

Allen Goldstein
Jerry Stenbakken
Tom Nelson
NIST SynchroMetrology Laboratory

- We are the only NMI to offer calibrations for PMUs
- Combine NIST Capabilities in Time Metrology and in Waveform Metrology
- Developed Laboratory to Perform Calibrations of Phasor Measurement Units (PMUs)
- Provide Assistance to Manufacturers and Utilities on Design and Use of PMUs
- Developing capability to calibrate PMU calibrators
Improved PMU Performance

Before

After

Figure IH1A. Total Vector Error (TVE) for the voltage channels VA (top), VB, VC, and V1 (bottom) versus interharmonic frequency (10% of fundamental magnitude).

IH12_4_16_09cut

IH12_6_22_09cut
Standards used by PMUs

- IEEE Std. C37.118.1-2011 “Synchrophasor measurement”
- IEEE Std. C37.118.2-2011 “Synchrophasor communications”
- IEEE Std. 754-1985 “Standard for Binary Floating Point Arithmetic”
- IEC 61850-90-5 “Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118“
- Various communications standards (Ethernet, TCP, UDP, etc.)
- Various timing standards (GPS, IRIG Std. 200-04, Universal Time Coordinated (UTC), IEEE Std. 1588, etc.)
Conformance is necessary:
PMUs must be interoperable in a very large system!

- 21 or more PMU manufacturers
- More than 50 different models of PMU
- PMU functions included in “multifunction devices”:
  - protective relays
  - digital fault recorders
  - power quality meters
- PMUs will be used in almost every power transmission system worldwide.
- Each PMU has 18 or more configurations of nominal frequency (F0), reporting rate (Fs), and class (M or P)
Measuring PMU electrical conformance

- **IEEE Std. C37.118.1-2011 Section 5: Synchrophasor measurement requirements and compliance verification**
  - 5.5.5 Steady state compliance:
    - Signal frequency range tests *(up to 100 tests per configuration)*
    - Signal magnitude tests *(up to 20 tests/configuration)*
    - Harmonic distortion tests *(50 tests /configuration)*
    - Out of band interfering signals *(50 to 100 tests/configuration)*
  - 5.5.6 Dynamic measurement bandwidth (modulation tests) *(up to 100 tests/configuration)*
  - 5.5.7 Dynamic ramp tests *(2 tests/configuration)*
  - 5.5.8 Dynamic step tests *(40 tests/configuration)*
  - 5.5.9 Measurement reporting latency *(1 test)*

* 4 tests of 10 iterations each
Jerry Stenbakken and the first NIST PMU steady state calibration system

Far left: Jerry Stenbakken, middle: NIST’s first PMU dynamic test system, far right: commercially available, fully automated PMU calibration system.

- Voltage TVE (%)
- Frequency error (Hz)
- ROCOF Error (Hz/s)

- TVE_Limit
- MaxTVE_VC
- MaxTVE_VB
- MaxTVE_VA
- MaxTVE_V+
- Min_FE
- Max_FE
- FE_Limit (pos)
- FE_Limit (neg)
- RFE_Limit (pos)
- RFE_Limit (neg)

Input Frequency (Hz) 55.0 57.0 59.0 61.0 63.0 65.0
Voltage TVE 0.0 0.5 1.0 1.5
Frequency error 0.000 0.002 0.004 0.006
ROCOF Error 0.0 0.2

Future Changes Expected for NIST Test Systems

• PMUs with IEEE 1588 Synchronization Capability

• New NIST Developed Amplifiers to the Dynamic test system for Increased Stability and Reduced Noise

• Beyond PMUs: Merging Units, Process Bus
2013 Accomplishments

- Implement New C37.118.1-2011 Tests
- 61850-90-5 Message Transmission
- Latency testing
- Developed Tests for PMU Calibrators
- Calibrated a PMU Calibrator
- Began a PMU test lab round robin
- Recommendations based upon PMU performance data submitted to PSRC WG H11 were accepted and included in C37.118.1a-2014
2014 Plans and Expectations

- Industry test lab for PMU calibrations by 2015
- Calibrate PMU Calibrators
- Continue a PMU test lab round robin
- Publish NISTIR on PMU assessment
- Publish paper on use of time synchronization in electric power transmission and distribution
Smart Grid Sensors
Jerry FitzPatrick, Paul Boynton, Kang Lee

- Basic Electrical Quantities
- Environmental Monitoring
- Interconnection Monitoring
- Asset Condition Monitoring

FCI – Fault Current Indicator
CT – Current Transformer
PT – Potential Transformer
SCADA – Supervisory Control and Data Acquisition
RTU – Remote Terminal Unit
AMI – Advanced Metering Infrastructure

Dispatcher
Smart Meter
Application
Substation RTU

Wireless Communication
Linearizing Circuit
Digitizer for Linear Input
Post CT/PT
Optical CT/PT

CT
PT
Identified Needs

Near
• Support Standards Development for Smart Sensors
• Load and Fault Dynamic Range R&D
• Models and Parameters for New loads and Sources
• Support Enterprise Bus Standards Development

Medium Term
• Facilitate Certification for Smart Sensors
• Support Development of an Optimized Deployment and Strategy and Analysis Tool

Long Term:
• Clamp-on Device Voltage Measurement Technology Development
• Mobile Calibration for Smart Sensors
Future Synchrophasor/Sensor Work

Synchrometrology:
• Commercial PMU capability study – 2013
• IEEE International Conformity Assessment Program (ICAP) for PMUs
• PMU Interlaboratory Comparison – kickoff 2013

NIST SG Testbed
• Integrate many aspects of the Smart Grid several interconnected laboratories with a metrology focus: performance, communications, timing, cybsecurity, etc
• Integrate PMU timing testbed with SG testbed
• Perform sensor studies - under real-world dynamically-changing power conditions
Thank you!