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…”
Agenda

• Background on NIST Smart Grid Interoperability Framework
• Smart grid conceptual model
• Communications pathways scenarios
• CPS ontology for the grid
• Key Framework Messages
  – Operations
  – Economics
  – Cybersecurity
  – Testing & Certification
• Ways to be involved
Review: 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 Advanced Network Technologies Division and Computer Security Division, Information Technology Laboratory

http://dx.doi.org/10.6028/NIST.SP.1108r3
Review: Interoperability Frameworks to date

NIST Special Publication 1108

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

2010

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

2012

NIST Special Publication 1108r3

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

2014
Motivations

- Technology is advancing rapidly
- Evolving capabilities bring:
  - New opportunities
  - New concerns / challenges
  - Structural change
- Modular and scalable technologies enable:
  - Disaggregation of system physics
  - Hyper-local optimization
  - A new set of cascading concerns
- Distribution models diversifying
- Interoperability more critical than ever
- Interoperability more challenging than ever

Framework 4.0 Themes

- Structural changes are occurring in the grid
- System complexity is increasing
  - Interoperability is a critical element of modern grid function
- No single architecture is correct
  - Common trends
  - Unique conditions
- Grid architectures affect:
  - Operations
  - Economics
  - Cybersecurity
- As actors take on new roles within the system and new economic forces emerge, interoperability gains new dimensions
  - Testing & Certification
Conceptual Model

- Generation including DER
  - Technology diversity
  - Physical proximity to transmission, distribution + customer domains

- Intelligent distribution system
  - Increasing importance (location + size)
  - Improved controllability + intelligence
  - Connected to service provider domain (e.g., congestion mitigation)

- Empowered consumers
  - Operations & intelligence enters customer domain
  - Customer diversity incorporated
Transmission Domain

Transmission

Operations

Markets

Storage

Substation

Sag

Distribution

Source: DRAFT NIST Smart Grid Framework 4.0

Transmission including DER

External Communication Flows
Internal Communication Flows
Electrical Flows
Domain

Control Measure Protect Record Stabilize Optimize

Generation including DER

NIST Smart Grid Program
NIST smart grid program

Distribution Domain

Distribution

Operations

Markets

Transmission

Distributed Generation

Distributed Storage

Substation

Fault Circuit Indicator

N.O. Switch

Cap Bank

Sectionalizer

Reclosers & Relays

Service Provider

Customer

Generation including DER

External Communication Flows

Internal Communication Flows

Electrical Flows

Domain

Source: DRAFT NIST Smart Grid Framework 4.0
Customer Domain

Source: DRAFT NIST Smart Grid Framework 4.0
Markets Domain

Markets

- Distribution
- Transmission
- Operations
- Service Provider
- Customer
- Generation including DER

Markets

- Market Ops
- Market Management
- DER Aggregation
- Trading
- Ancillary Ops
- Retailing
- Wholesaling

Source: DRAFT NIST Smart Grid Framework 4.0
Operations Domain

Operations

Network Operations
- Fault Analysis
- Monitor
- Control
- Load Control
- Reporting & Statistics
- Analysis

Transmission

Generation including DER

Distribution

Service Provider

Customer

Markets

Supply Chain / Logistics

Maintenance & Construction

Financial

Extension Planning

Ops Planning

Meter Reading & Control

Communications Network

Security Management

Records & Assets

Source: DRAFT NIST Smart Grid Framework 4.0

External Communication Flows
Internal Communication Flows
Electrical Flows
Domain
The CPS Framework—A Tool for the Smart Grid

Jargon surrounds the electrical grid:

- *Intelligence moving to the edge*
- *Data tsunami*
- *Grid architecture*
- *Cloud / fog computing*
- *Smart grid*
- *Microgrid vs backup power*

The cyber-physical systems (CPS) framework provides a vocabulary of energy sector semantics, or ontology, through evaluation of CPS framework aspects and concerns.
## CPS Aspects and Concerns

### Functional
- Actuation
- Communication
- Controllability
- Functionality
- Manageability
- Measurability
- Monitorability
- Performance
- Sensing

### Business
- Enterprise
- Cost
- Environment
- Policy
- Quality
- Regulatory
- Time to Market
- Utility

### Human
- Human Factors
- Usability

### Trustworthiness
- Privacy
- Reliability
- Resilience
- Safety
- Security

### Timing
- Synchronization
- Time Awareness

### Data
- Data Semantics
- Relationship between Data

### Boundaries
- Behavioral
- Networkability
- Responsibility

### Composition
- Adaptability
- Complexity
- Constructivity
- Discoverability

### Lifecycle
- Deployability
- Disposability
- Engineerability
- Operability
CPS Aspects and Concerns

- **Functional**
  - Actuation
  - Communication
  - Controllability
  - Functionality
  - Manageability
  - Measurability
  - Monitorability
  - Performance
  - Sensing

- **Business**
  - Enterprise
  - Cost
  - Environment
  - Policy
  - Quality
  - Regulatory
  - Time to Market
  - Utility

- **Human**
  - Human Factors
  - Usability

- **Trustworthiness**
  - Privacy
  - Reliability
  - Resilience
  - Safety
  - Security

- **Timing**
  - Synchronization
  - Time Awareness

- **Data**
  - Data Semantics
  - Relationship between Data

- **Boundaries**
  - Behavioral
  - Networkability
  - Responsibility

- **Composition**
  - Adaptability
  - Complexity
  - Constructivity
  - Discoverability

- **Lifecycle**
  - Deployability
  - Disposability
  - Engineerability
  - Operability

Note: Illustrative only
## Description of CPS Concerns for the Smart Grid

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Concern</th>
<th>Description</th>
<th>Grid Context for CPS Concern</th>
<th>Grid CPS Concern Description</th>
<th>Architecture Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional</td>
<td>Controllability</td>
<td>Ability of a CPS to control a property of a physical thing. There are many challenges to implementing control systems with CPS including the non-determinism of cyber systems, the uncertainty of location, time and observations or actions, their reliability and security, and complexity. Concerns related to the ability to modify a CPS or its function, if necessary.</td>
<td>• Controllability requires the codonization of sensing, processing and acting&lt;br&gt;• Multiple inputs are needed to make control decisions&lt;br&gt;• Most grid control systems and hardware were not designed to accommodate large numbers of DERs.&lt;br&gt;• More dynamic monitoring and control to respond to the dynamic network</td>
<td>• Ability to control grid properties (sense, process and change); e.g., intentionally change a phenomenon / property</td>
<td>• Coordination of sensing and processing functions to produce accurate control signals.&lt;br&gt;• Architectures need to support control applications that input and evaluate multiple optimization factors including carbon usage and market prices&lt;br&gt;• Architecture needs to support use of group commands (e.g. DNP3 settings groups) and third-party aggregator control of DERs&lt;br&gt;• Architecture support of faster input of sensor data from traditional SCADA devices and newer devices including phasor measurement units (PMUs)</td>
</tr>
<tr>
<td>Functional</td>
<td>Functionality</td>
<td>Concerns related to the function that a CPS provides</td>
<td>• The constant evolution of the power system creates new grid functions.&lt;br&gt;• Grid control functionality has expanded to include management of generation assets which require different functionality e.g. diverse generation assets require additional control functionality including distributed assets.</td>
<td>• Ability to provide grid functions e.g. control functions, sensing functions, service-related functions.</td>
<td>• Innovative grid technology needed to facilitate Power Markets, DERs, Microgrids, Electric Vehicles, etc.&lt;br&gt;• Architecture needs to support management of DERs constraints that differ from older types of generation.</td>
</tr>
<tr>
<td>Functional</td>
<td>Manageability</td>
<td>Concerns related to the management of CPS function.</td>
<td>• Need the ability to manage change across multiple devices at different grid levels.</td>
<td>• Ability to manage change internally and externally to the grid at the cyber-physical boundary e.g. digital equipment and actuators affected by EMC</td>
<td>• Communication topology views and key externally visible properties for multi-tier distribution communications needed for system control, substations, field operations, and Transmission/Distribution integration[^14]</td>
</tr>
</tbody>
</table>
Framework Themes through pathway scenarios

- Scenarios affect what we think about grid
  - Cybersecurity
  - Operations
  - Economics

- We can use the examples to explore
  - Common trends
  - Changing responsibilities
  - Unique considerations

- Scenarios help us understand value streams
  - Who is the customer in a High-DER architecture?
  - The role of interoperability in unlocking this value

- Testing & Certification growing importance
  - Claimed conformance vs actual performance
  - Actuation and controllability in every device
  - Diversified ownership, unified operation

- CPS ontology allows description and specification

**ENGAGEMENT OPPORTUNITIES**
Registration info on later slides

- **July 9, 2018:**
  Testing & Certification Workshop
  Washington, DC

- **July 24, 2018:**
  Communications Pathways & Ontology Workshop
  Gaithersburg, MD

- **August – October, 2018:**
  Regional operations & economics workshops
Sensing, actuation and control is moving towards the grid edge:
- Common trend across all scenarios
- Occurring in each domain
  - Transmission edge: PMUs and IEDs
  - Distribution edge: distribution automation devices & smart inverters
  - Customer edge: remote controllable appliances
- Operational efficiencies can be gained through local management
• As DERs increase, shared infrastructure becomes more important

• Shared infrastructure increases need for predictability
  – Physical predictability (e.g., IEEE 1547)
  – Communications predictability (e.g., IEC 61850)

• Shared infrastructure has benefits, possible risks
Operations Key Message: No single implementation

- Grid architectures are not mutually exclusive
- The examples allow us to explore technical aspects of interoperability
- No single architecture is “correct”
Operations Key Message: Diversified ownership

Diversifying asset ownership
• Common to all architecture examples

Demands increased interoperability

Requires Trustworthiness
• Extends beyond cybersecurity
  – Trustworthiness.Reliability
  – Trustworthiness.Resilience
  – Trustworthiness.Safety

• Architecture defines trustworthiness requirements
  – Device level trustworthiness
  – Microgrid level trustworthiness
  – Service provider level trustworthiness

Grid operation is highly interdependent with market structure, which in turn is limited by the nature of grid operations. Operations and market evolve coincidently and interdependently.
Interoperability can help to overcome the barriers of device specificity and support the marketing efforts and revenue outlook of new and existing grid services.

Organizational Strategy
1. Organizations invest in resources and capabilities that strengthen their core competencies.
2. Investments may commit an organization to certain competitive strategies and business models.
3. Firms may discover subsequent, synergistic opportunities.

Smart Grid Context
1. Asset specificity often results from efforts to meet technical requirements and contribute to a value chain.
2. Specificity may then act as a barrier to broader or further utilization of devices and systems.
3. Interoperability offers a strategy set through which to reduce “specificity barriers”.

Value chains and value networks
The value of DER and conventional assets to the electric grid will improve as interoperability enables these resources and capabilities to make additional contributions across the sector’s value network.
Economics Key Message: Customer Empowerment

Interoperability is crucial to customer empowerment.

1. Enabling customers to be better informed regarding their own electricity-use decisions.
   a. Improved utilization of current assets
   b. Better decision making with respect to technological adoption
   c. Accurate signals are critical to economic efficiency

2. Enabling a plug-and-play environment.
   a. Expectation that devices purchased will work with rest of the system
   b. Devices can be selected for customer optimality
   c. Reduced entry barriers and transaction costs of integrating customer equipment

3. Informational improvements may contribute to greater customer agency
Interoperability can counter rising transaction and production costs associated with the increasing complexity of interaction among diverse organizations of varying regulatory status.

1. Value chain complexity is rising with asset specificity
2. The regulatory status of firms varies across the value chain
3. Coordinating value-adding activities is costly

Impact on Cost Structures

Transaction costs are rising in salience

“Current writing has helped bring out the point that market failure is not absolute; it is better to consider a broader category, that of transaction costs, which in general impede and in particular cases completely block the formation of markets. It is usually though not always emphasized that transaction costs are costs of running the economic system”.

(Arrow 1969)

Interoperability strategies can directly address cost escalation due to complexity
Effective and efficient testing and certification regimes are needed to ensure that devices, systems, and components perform as expected and are fit for purpose.

1. Achieving interoperability will require initial and ongoing testing of devices, systems, and systems of systems.

2. Interoperability investments constitute cooperative strategies for improving the efficiency of the electric grid.

3. Some interoperability benefits are likely to be split between stakeholder groups.

4. Testing and Certification regimes can help to identify and discipline problem areas/actors as well as inform subsequent strategy formation and product development.
Cybersecurity Key Message: Requirements & responsibility

- Cybersecurity risk profile for the smart grid
- Structural considerations
  - Business/mission requirements similar across architectures
  - Responsibilities may change, however
  - Considerations for cybersecurity activities

For more information on NIST Cybersecurity Framework: https://www.nist.gov/cyberframework
Cybersecurity Key Message: Known issues, new interfaces

Logical Reference Model for Smart Grid Communications

Source: NISTIR 7628 Guidelines for Smart Grid Cyber Security, 2010

Logical Reference Model for High-DER Scenario

Multi-Level Hierarchical DER Scenario

Source: DRAFT NIST Interoperability Framework v4.0
Testing & Certification: Establishing context

Identified SG Standard List of NIST Framework R3.0

Smart Grid Standards for Evaluation (244 Standards)

NEW STANDARDS
• New Standards
• New versions of old standards


DSO Priority List


SEPA/SGIP SG CoS List

Source: http://www.gridstandardsmap.com/
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Testing & Certification: Preliminary Data Analysis

Smart Grid Standards and Associated Testing & Certification

<table>
<thead>
<tr>
<th>Standards Functional Category</th>
<th>Number of Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information Model</td>
<td>16/61</td>
</tr>
<tr>
<td>Communications Protocol</td>
<td>25/114</td>
</tr>
<tr>
<td>Performance</td>
<td>14/30</td>
</tr>
</tbody>
</table>

- Communication: 36/114
- Information Model: 16/61
- Performance: 14/30

Standards in Category, Testing & Certification Programs, Total Standards Reviewed.

NIST smart grid program
T&C Key Message: Gaps persist in assuring interoperability

- There is a growing number of standards that are the foundation of grid modernization.
- There remains a gap in the availability of testing and certification programs to ensure that standards have been implemented appropriately and consistently to support interoperability of devices and systems.
- Even as industry coalesces around a subset of standards and options, the real universe of standards and applications is diversifying.
- Some standards are showing convergence on a subset of requirements but on parallel pathways.
T&C Key Message: Implementation complexity

Communication Protocols

- IEEE Standard 2030.5 (SEP2)
- IEEE Standard 1815 (DNP3)
- SunSpec
- Modbus
- Others...

Information Models

- SEP2 DER
- IEC 61850
- SunSpec
- Others...

Implementations

- Others...
T&C Key Message: Interoperability profiles

- A profile is a description of a well-defined subset of the standard that has been agreed upon by a user community, testing authority or standards body.

- The specification and use of profiles allows the interoperability gap to be narrowed by reducing the degrees of freedom of implementation flexibility in the context of interest by the device supplier, implementer and system owner.

- Interoperability profile can
  - Narrows constraints and provides uniformity
  - Supports multi-vendor interoperability
  - Lowers cost of system integration
Stakeholder Engagement: Testing and Certification Workshop

Date: July 9, 2018
Location: Washington Hilton, Washington, DC
Co-sponsor: SEPA

Objectives: To explore underlying drivers for the current state of smart grid interoperability testing and certification, and examine interoperability profiles for smart grid standards as a means to accelerate the development of testing and certification programs.

Key Questions:
• What is limiting the development and use of T&C in the smart grid ecosystem?
• What essential elements are needed to formulate an interoperability T&C program?
• How would you prioritize operational interfaces for T&C development?

Workshop webpage:
Objectives: To review communication pathways scenarios and their relationship to grid operations, cybersecurity, economics, and associated requirements for interoperability testing and certification. We will also review a mapping of NIST’s Cyber-Physical Systems (CPS) Framework aspects and concerns to the smart grid, which provide an ontology that can help clarify issues and capabilities that arise—or are needed—in this increasingly complex space.

Key Questions:
• What are the errors and deficiencies in the NIST communications scenarios?
• How can the Smart Grid Conceptual Model be used to convey grid scenarios?
• What improvements are necessary for the CPS concerns ontology for the grid?

Framework webpage:
Stakeholder Engagement: Regional Workshops

Date: August-October, 2018
Location: Northeast, Midwest, West Coast, and Southeast
Co-sponsor: NARUC

Objectives: To explore regionally specific issues affecting grid operations and economics. The workshops will be held at state Public Utility Commissions, allowing participants to learn about interoperability issues and concerns relevant to the respective commission and its stakeholders.

Key Questions:
• Locally specific questions will be developed in partnership with NARUC and the local Commission to explore relevant aspects of the communications pathways scenarios and associated economic and operational issues.

See Framework webpage for updates:
THANK YOU