ISGT Panel: Innovative Research at the NIST Smart Grid Testbed

- Overview of the Smart Grid Testbed – Paul Boynton/Avi Gopstein
- Smart Grid Sensor Technologies – Jerry FitzPatrick
- Smart City Applications – Marty Burns

NIST Smart Grid Testbed

April 26, 2017

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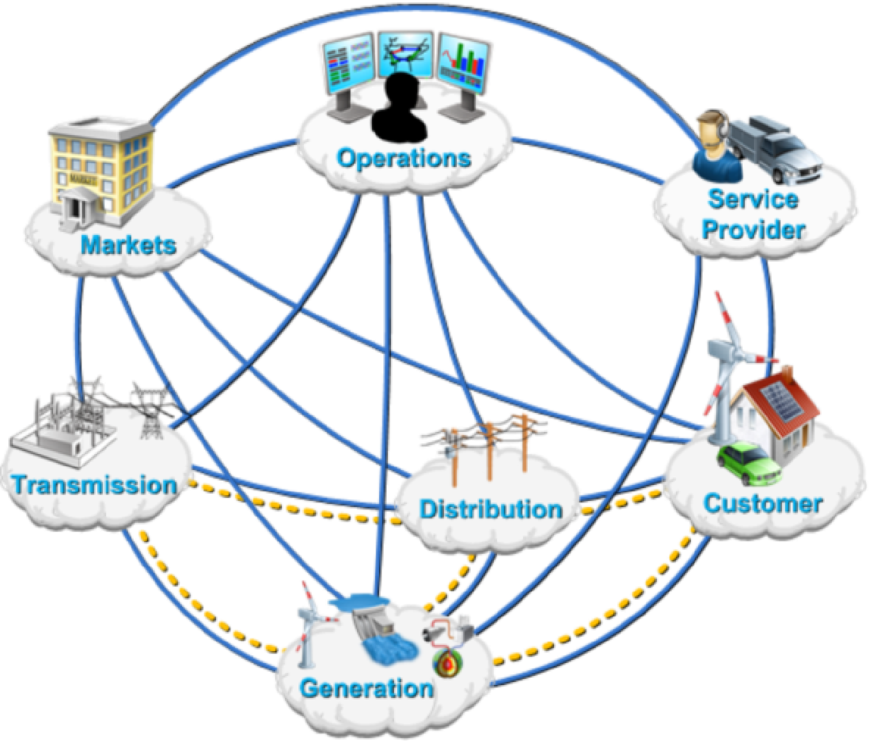
NIST Smart Grid Research

- **Key factors**
  - The future of the grid is uncertain
  - Interoperability enables communication, aggregation and optimization across multiple actors
  - Technical innovation is expanding markets
  - New technology + expanding and overlapping markets = disruptive opportunity
  - Grid as platform, services provided by and between new groups



NIST Smart Grid Testbed Program

- **Measurement science key to grid observability**
  - Timing
  - Measurement uncertainty
  - System modeling
  - Cybersecurity through physics
  - Communications
  - Synchrometrology
  - Applications

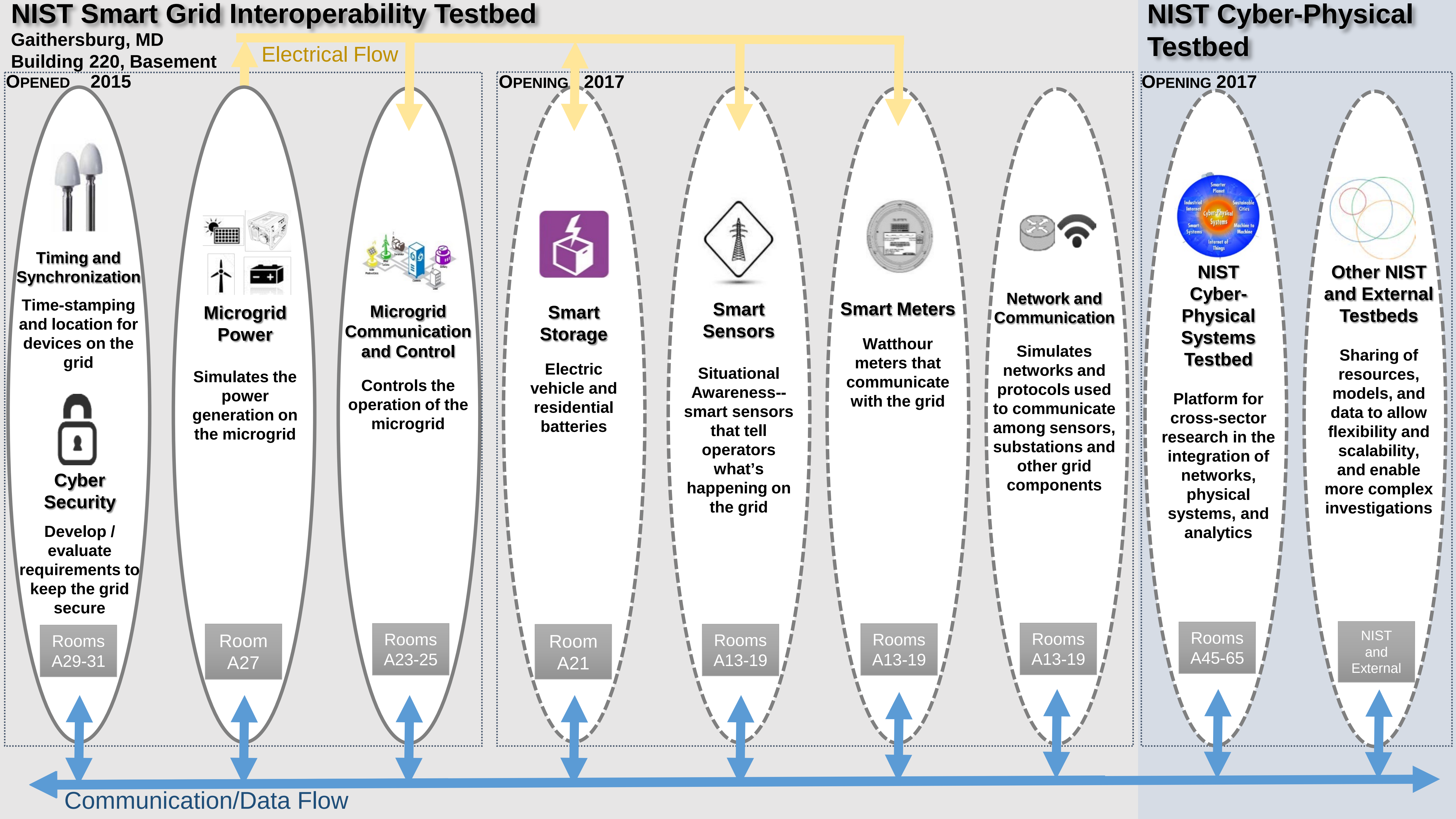
Key Testbed Characteristics

- **Integrative**
  - Interconnected modules
  - Diverse expertise
- **Reconfigurable and Reproducible**
  - Easily re-configured
  - Reproducible experiments
- **Scalable**
  - Federated experiments across testbeds
- **Usable**
  - Composable
  - Collaborative
  - Coordinated

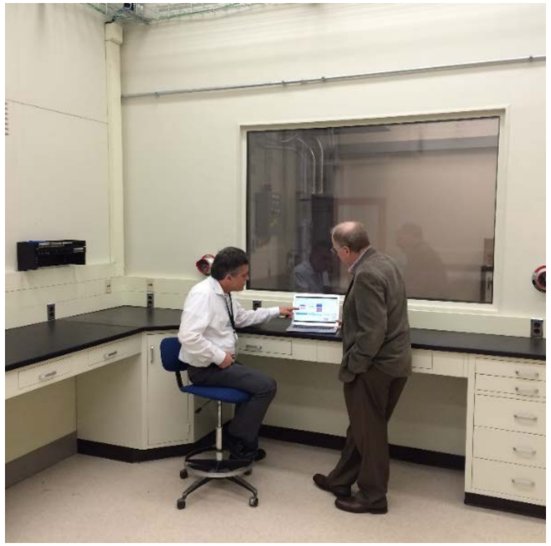
NIST Smart Grid Testbed Development

- **Objectives**
  - To provide the foundational infrastructure for smart grid interoperability research
  - To accelerate the development of smart grid interoperability standards by addressing the measurement needs of smart grid industry
  - To develop and participate in a community of testbeds
    - Workshops held in March 2014 and February 2015
    - Identified gaps and challenges to testbeds
    - Singled out key design principles

- **Scope**
  - Designed to be composable, collaborative, and coordinated
  - Perform measurements of system-level, end-to-end device level smart grid performance and interoperability
  - Measure and characterize key components, standards, and protocols of smart grid systems and devices
  - At present, focus research on microgrids/distribution


NIST Smart Grid Interoperability Testbed
Gaithersburg, MD
Building 220, Basement
Electrical Flow
NIST Cyber-Physical Testbed
OPENED 2015
OPENING 2017
OPENING 2017
Timing and Synchronization
Time-stamping and location for devices on the grid
Cyber Security
Develop / evaluate requirements to keep the grid secure
Rooms A29-31
Microgrid Power
Simulates the power generation on the microgrid
Room A27
Microgrid Communication and Control
Controls the operation of the microgrid
Rooms A23-25
Smart Storage
Electric vehicle and residential batteries
Room A21
Smart Sensors
Situational Awareness-- smart sensors that tell operators what's happening on the grid
Rooms A13-19
Smart Meters
Watthour meters that communicate with the grid
Rooms A13-19
Network and Communication
Simulates networks and protocols used to communicate among sensors, substations and other grid components
Rooms A13-19
NIST Cyber-Physical Systems Testbed
Platform for cross-sector research in the integration of networks, physical systems, and analytics
Rooms A45-65
Other NIST and External Testbeds
Sharing of resources, models, and data to allow flexibility and scalability, and enable more complex investigations
NIST and External
Communication/Data Flow

NIST Smart Grid Testbed Operation



- **Smart Grid Interoperability Test Bed operational**
  - Microgrid Facilities (AC and DC Grid Emulators, Smart Inverters)
  - Timing and Synchronization / Cybersecurity (GPS Antenna, IEEE 1588 clocks, Network Switches)
  - Interoperability test of smart sensors for Smart Grid
  - NIST Multi-Laboratory effort:
    - Engineering Laboratory
    - Physical Measurement Laboratory
    - Information Technology Laboratory
    - Communication Technology Laboratory
  - Testbed safety monitoring and daily operational coordination

- **Examples of significant activities**
  - Standards and Test for Microgrid Interconnection Equipment and Controllers (SGIP PAP 24) – *Hefner*
  - Develop Interoperability Test Methods for Smart Sensors (e.g. MUs) for smart grids based upon IEC standards - *FitzPatrick*
  - The Use of Synchrophasor Measurements in Electric Power Systems Protection and Control Applications - *Gharavi, Anand*

Microgrid Interoperability Facility

- Addresses metrology needed for interoperability of advanced microgrid devices and systems
- Extensible to all aspects of multilevel distributed control
- Focused on unique NIST mission of Smart Grid interoperability and leverages SGIP activities
- Incorporates elements of many of the projects in the NIST smart grid portfolio
- Coordinated with other agencies and industry programs
- Aligned with partner test bed architectures to enable interchangeability of devices between test beds
- Support standard development (IEEE 1547 series, IEEE p2030.7, IEEE p2030.8)

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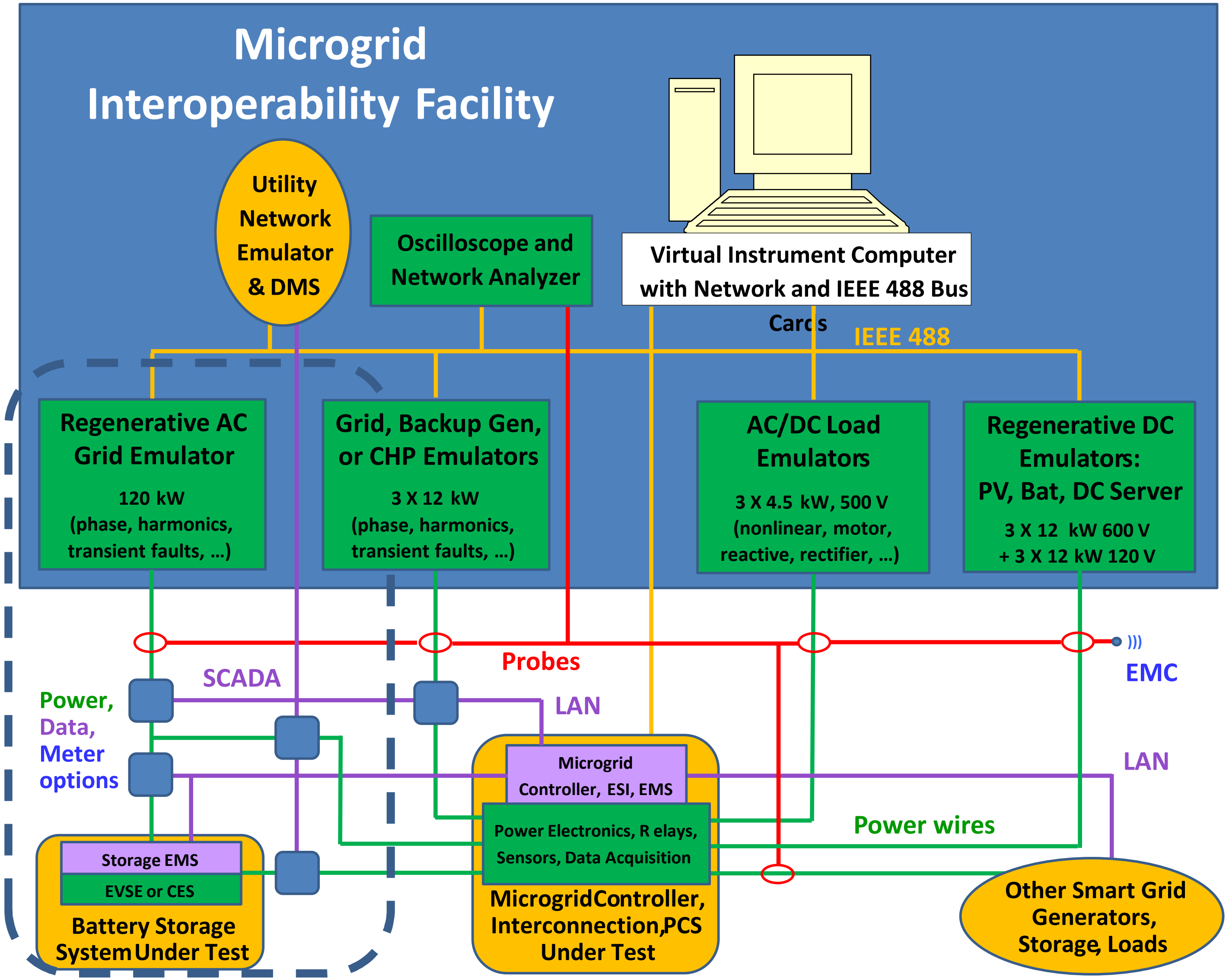
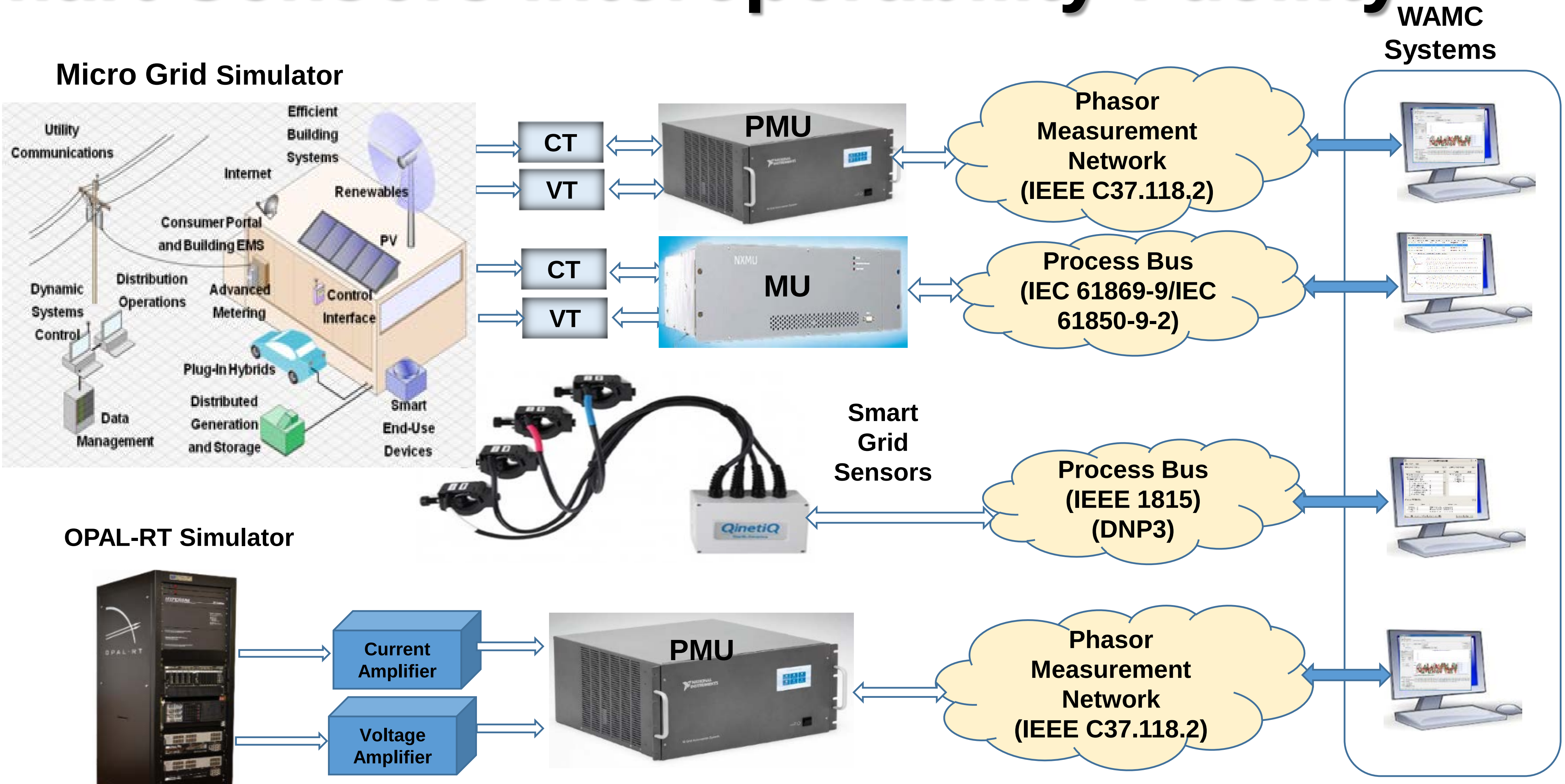


Smart Sensors Interoperability Facility



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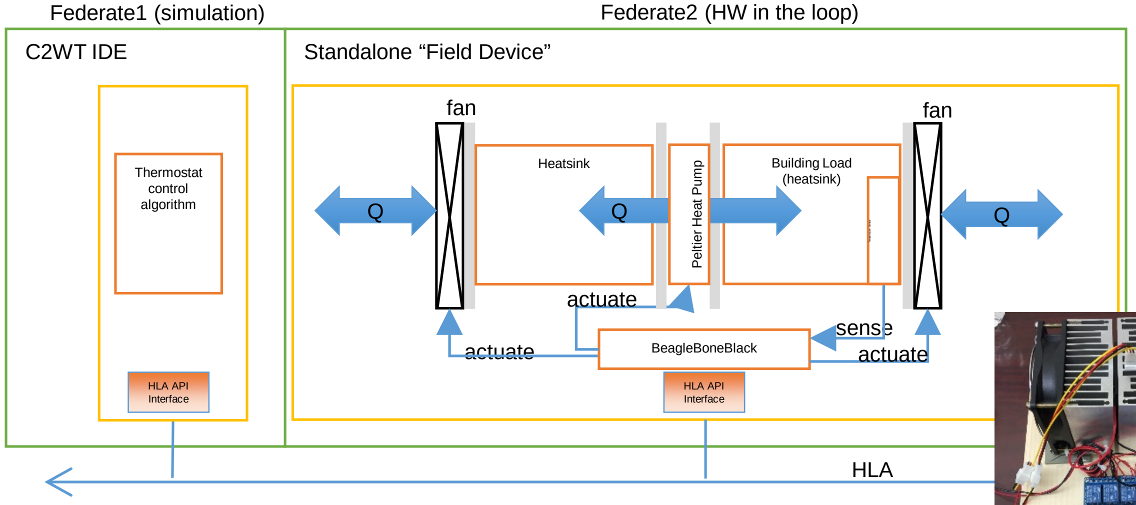
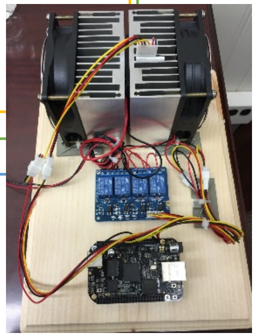
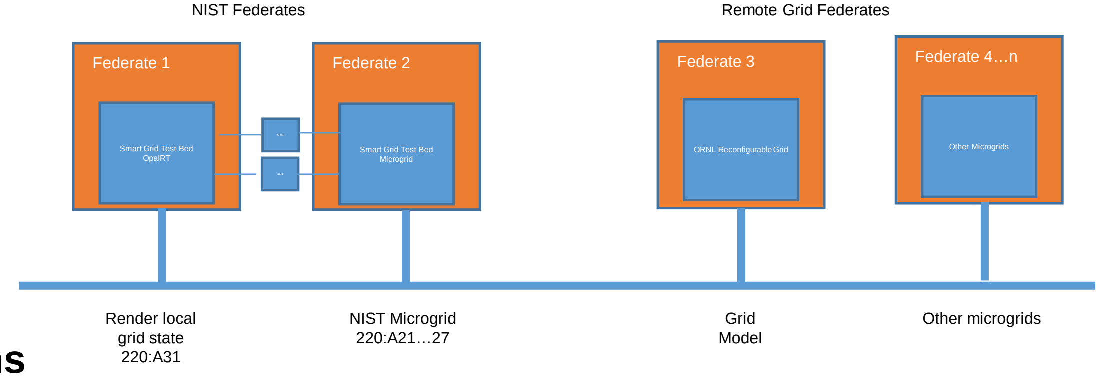
Federated Experiments

- Use Case: Use a software-implemented Thermostat to control a hardware in the loop "HVAC System" emulation
- Use Case: Use a physical emulation of a grid segment at one lab, along with microgrid simulations at other labs to analyze behavior of a grid of microgrids
- Use Case: Transactive Energy Challenge for comparative analysis of energy markets







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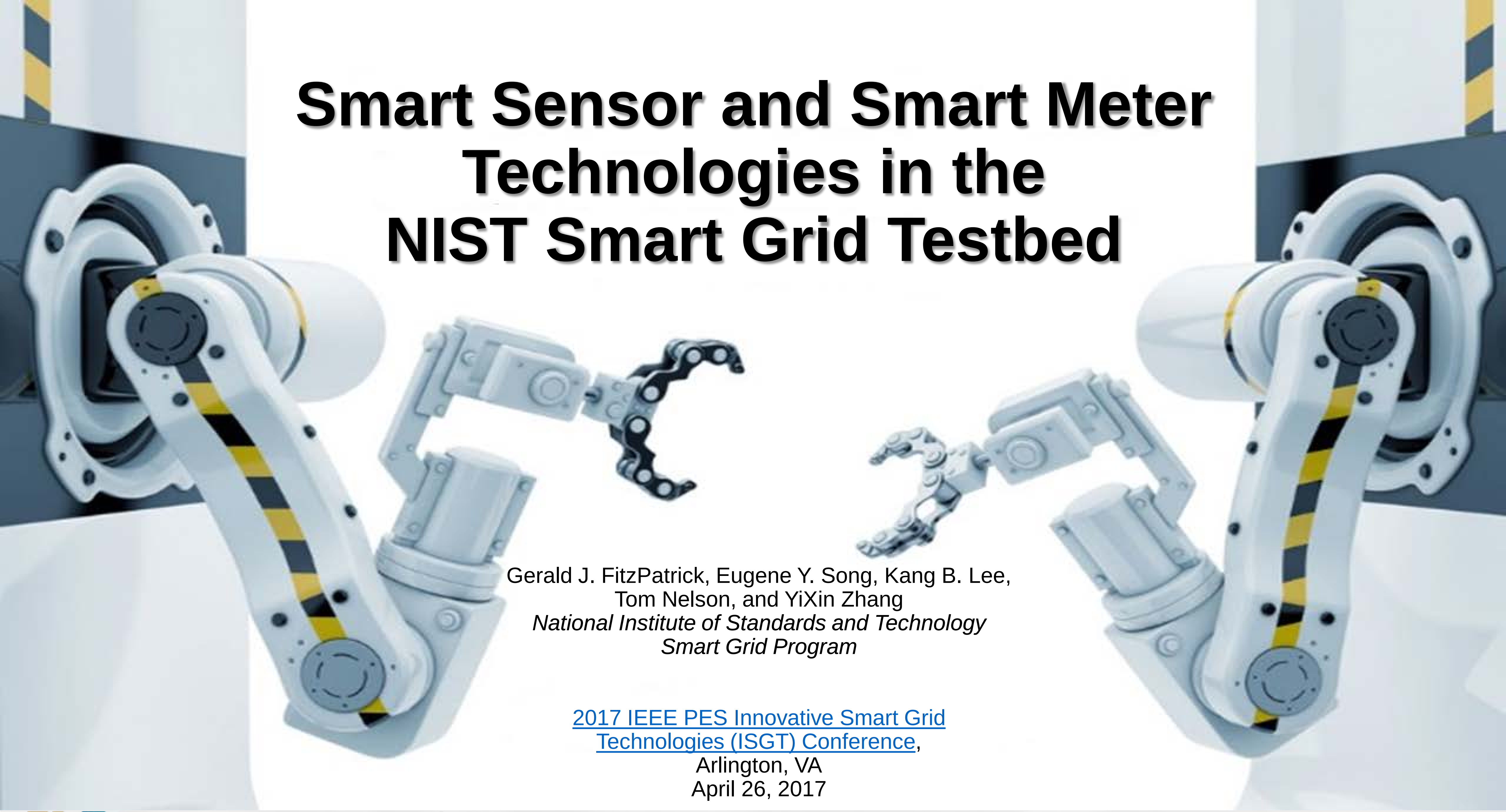
Thank You!



Smart Sensor and Smart Meter Technologies in the NIST Smart Grid Testbed

Gerald J. FitzPatrick, Eugene Y. Song, Kang B. Lee,
Tom Nelson, and YiXin Zhang
National Institute of Standards and Technology
Smart Grid Program

2017 IEEE PES Innovative Smart Grid Technologies (ISGT) Conference,
Arlington, VA
April 26, 2017

Energy Independence and Security Act

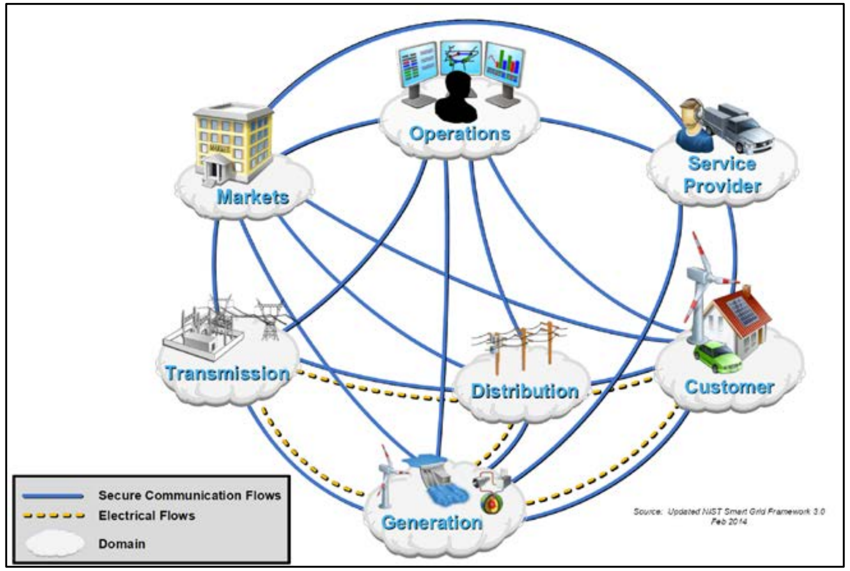
NIST has *"primary responsibility to* ***coordinate*** *development of a* ***framework*** *that includes protocols and model standards for information management to achieve* ***interoperability*** *of smart grid devices and systems…"*

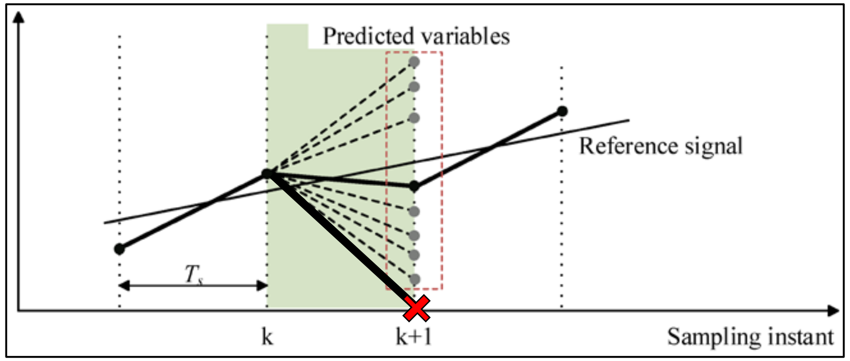
Uncertainty is a dominant challenge

- **Grid is highly distributed and complex**
  - Increasing diversity of devices, resources, and controls

- **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**
  - Models of new grid dynamics
  - Improved measurements of dynamic voltage current, power , and energy (lower measurement uncertainties)
  - Networked measurements
  - Diversified applications
  - Expanding customer-base





NIST SG Testbed: An Integrated Approach to Smart Grid Testing

- Interoperability + Performance
- 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

SGIP Smart Grid Interoperability

NIST Measurement Science

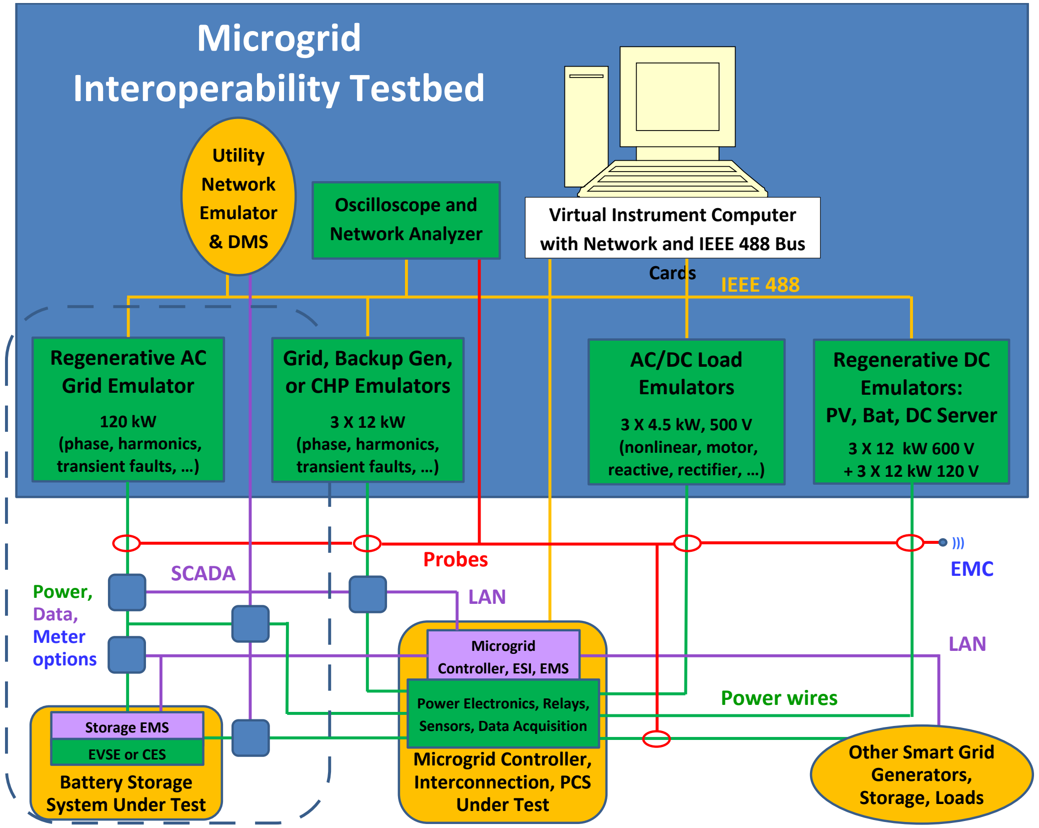
DOE/DOD Labs, Test & Certification

ESI, EMS, Microgrid & Storage functions

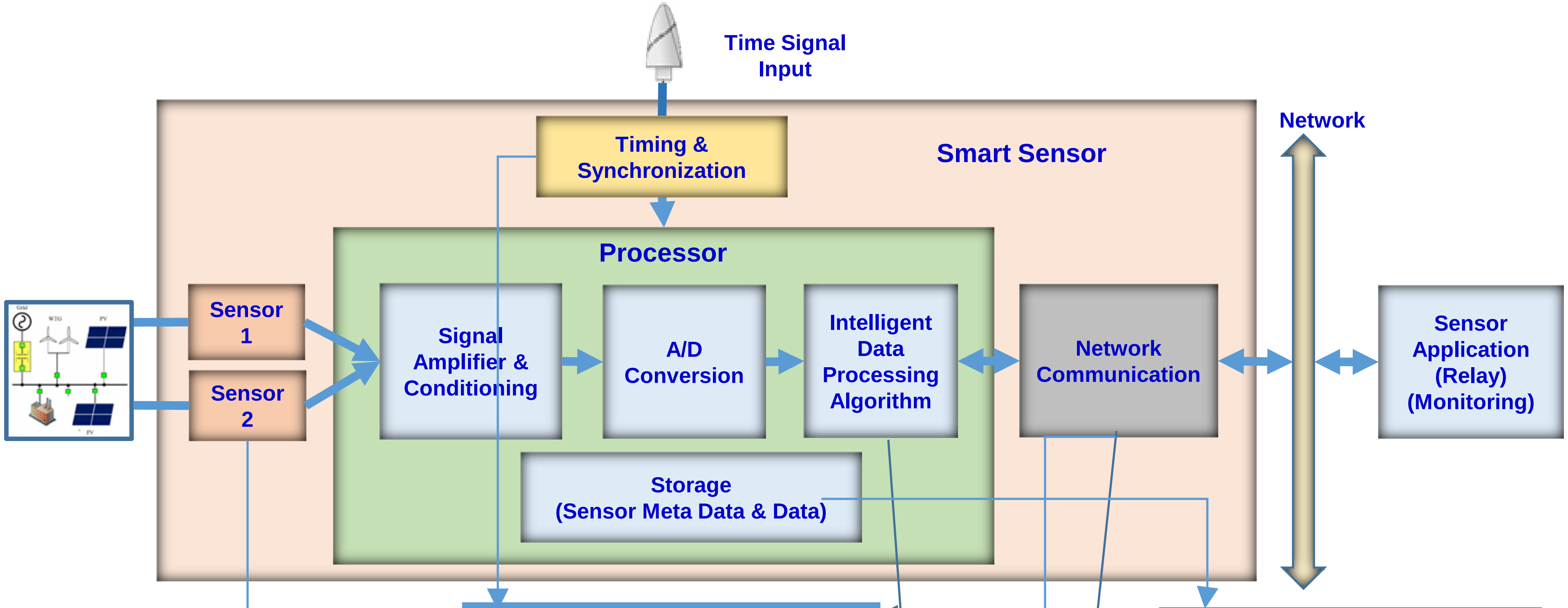
IT Networks, Cyber Security, EMC, Sensors & Smart Meters

Power Electronic Interconnection Equipment

Grid-Interactive Microgrid, DER & Smart Appliances



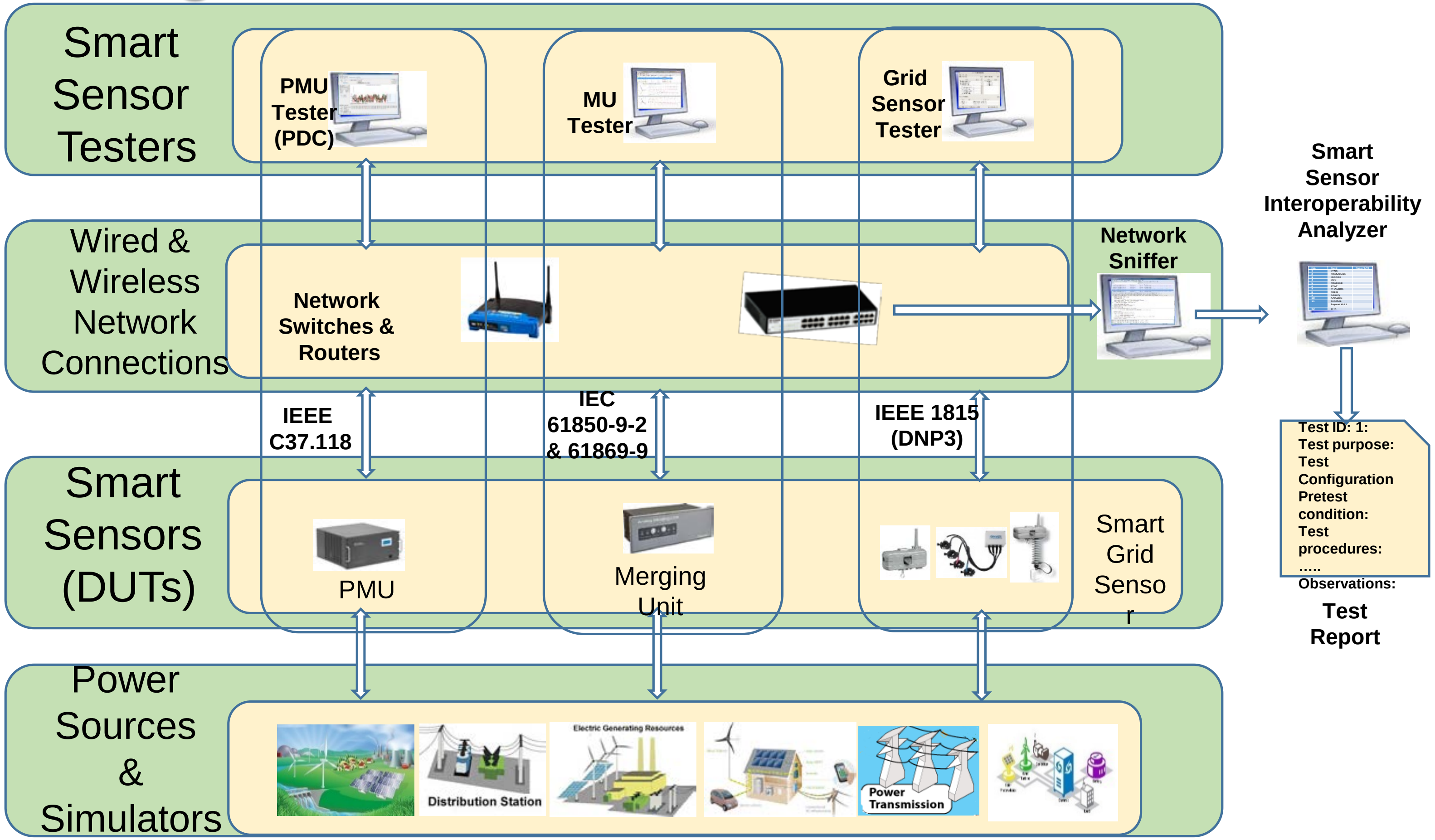
Smart Sensor Testing



- Performance test
  - Accuracy
  - Timing
- Conformance Test (functions)

- Interoperability **Test**
- Wired and wireless Network Performance Test

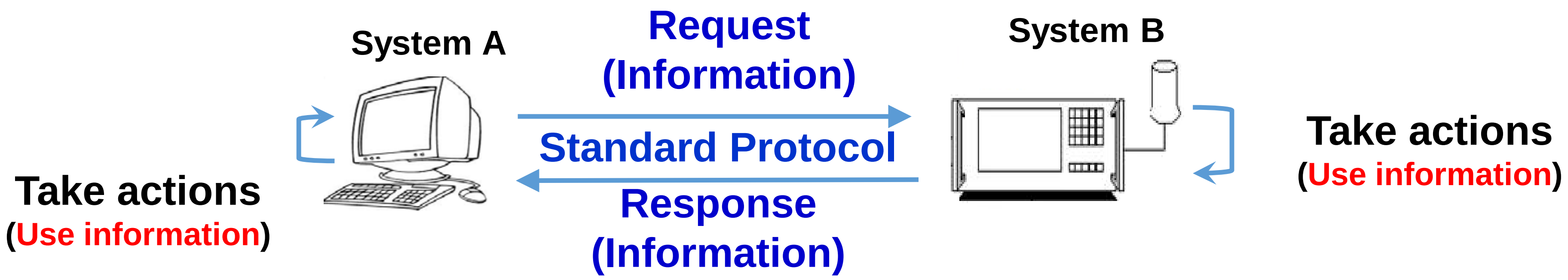
Testing Framework & Testbed for Smart Sensors



Interoperability - Modified IEEE Definition

Interoperability :

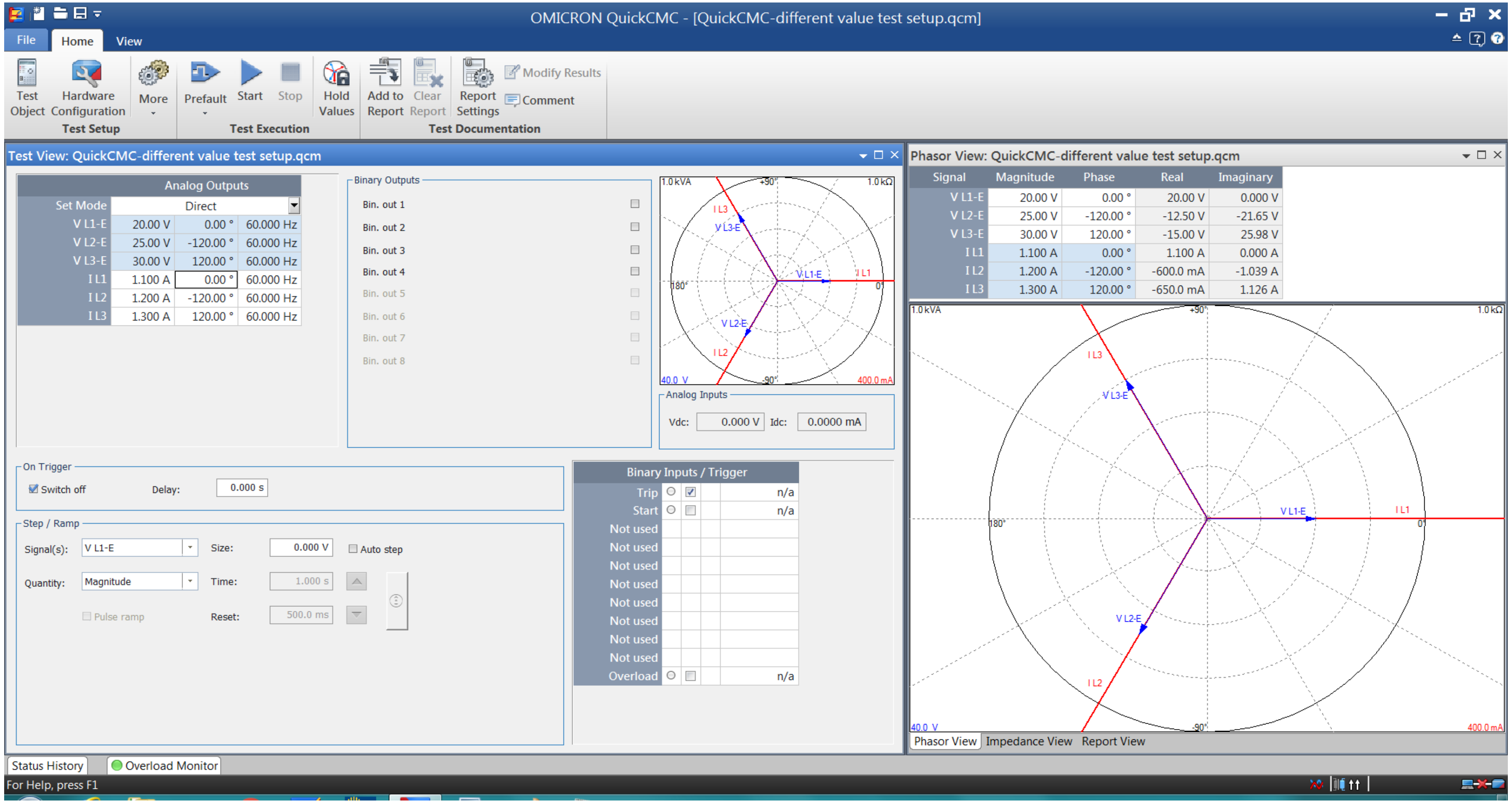
- **The ability of two or more systems to exchange information and to use the information that has been exchanged <u>through a standard communication protocol in order to achieve the specific functions or goals</u>**



Need For Interoperability Testing

- Smart Grid requires implementation of a lot more devices and their applications
- Device integration has been proved to be one of the bottlenecks in implementing smart devices
- The cost of solving the interoperability problems can easily exceed the cost of the sensor itself
- Technical standards often are not clear and/or strict enough to ensure interoperability.

Example of the Calibrator Outputs



Three phase voltage and current signals generated by the calibrator

Example 1: Interoperability Test for Commercial PMUs

Preliminary Results of Interoperability Test of IEEE C37.118 Standard-based Commercial PMUs

Interoperability Test		PMU1 (TCP)	PMU2 (TCP)	PMU3 (TCP)	PMU4 (TCP)	PMU5 (UDP)	PMU6 (TCP)	PMU7 (TCP)	PMU 8 (TCP)
Turn Off	Procedures	P	P	P	P	P	P	P	P
	Command	P	P	P	P	P	P	P	P
	Response	P	P	P	P	P	P	P	P
Turn On	Procedures	P	P	P	P	P	P	P	P
	Command	P	P	P	P	P	P	P	P
	Response	P	P	P	P	P	P	P	P
Header	Procedures	P	P	P	P	P	F	P	P
	Command	P	P	P	P	P	P	P	P
	Response	P	P	P	P	P	F	P	P
CFG-1	Procedures	P	P	P	P	P	P	P	P
	Command	P	P	P	P	P	P	P	P
	Response	P	P	P	P	P	P	P	P
CFG-2	Procedures	P	P	P	P	P	P	P	P
	Command	P	P	P	P	P	P	P	P
	Response	P	P	P	P	P	P	P	P
Overall		P	P	P	P	P	P(80%)	P	P

P:Passed
F:Failed

Example 2: DNP3 Devices

- All three DNP3 sensors had a connection problem and failed when initially connected

- For the analog input test cases, no interoperability issues were identified.

Example 3: Interoperability Test for Commercial MUs Based on IEC 61850-9-2LE (Cont'd)

Preliminary Results of Interoperability Test of IEC 61850-9-2 LE Standard-based Commercial MUs

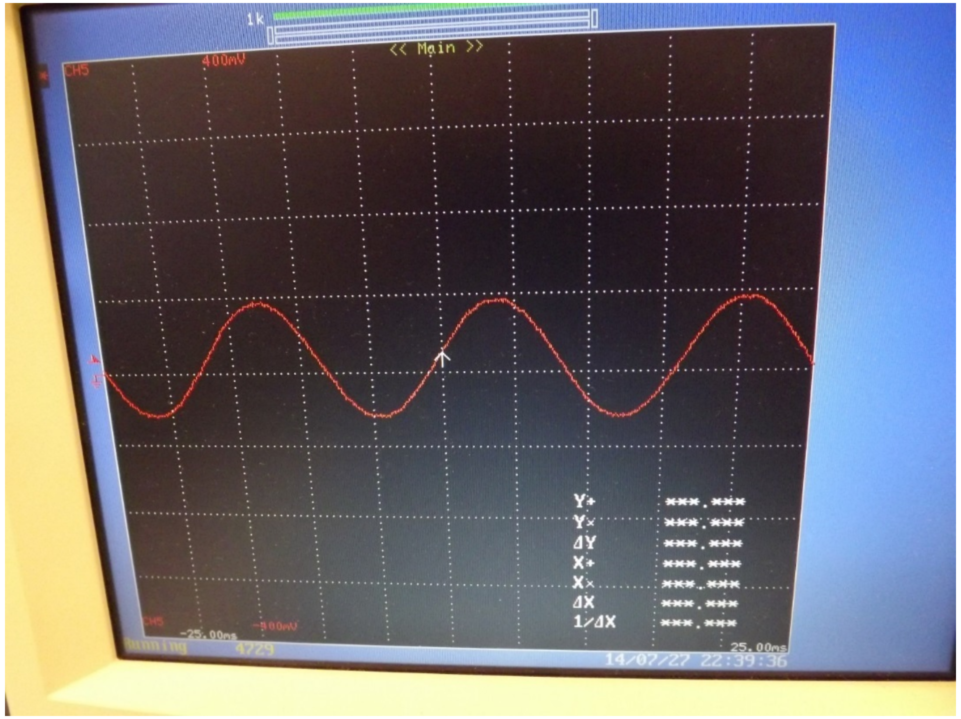
Test case SendMSVMessage	Vendor A MU	Vendor B MU	
	SV Stream 1 (80 samples/cycle)	SV Stream 1 (80 samples/cycle)	SV Stream 2 (256 samples/cycle)
Test procedures	Passed	Passed	Passed
MSVMessage	Passed	Passed	Passed
overall	Passed	Passed	Passed

One issue we encountered in the test is that the svID in the vendor B MU does not conform to 61850-9-2 LE specification.

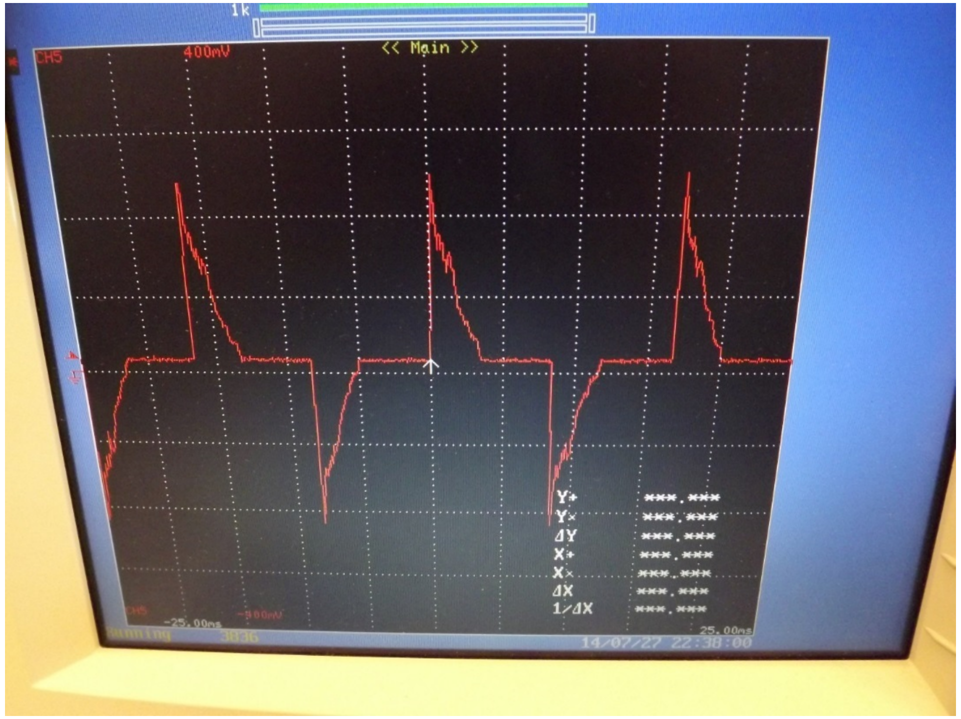
Smart Meters Research

- Testing of Smart Meters with real-world waveforms (examples on following slides)
- Auxiliary devices (communications) influence on meter accuracy
- EMI/EMC influence on accuracy
- Performance of Smart Meters as sensors in distribution grid
- Performance results will be used to improve ANSI Metering Standards
- DC metering for EVSE DC fast chargers
- Submetering

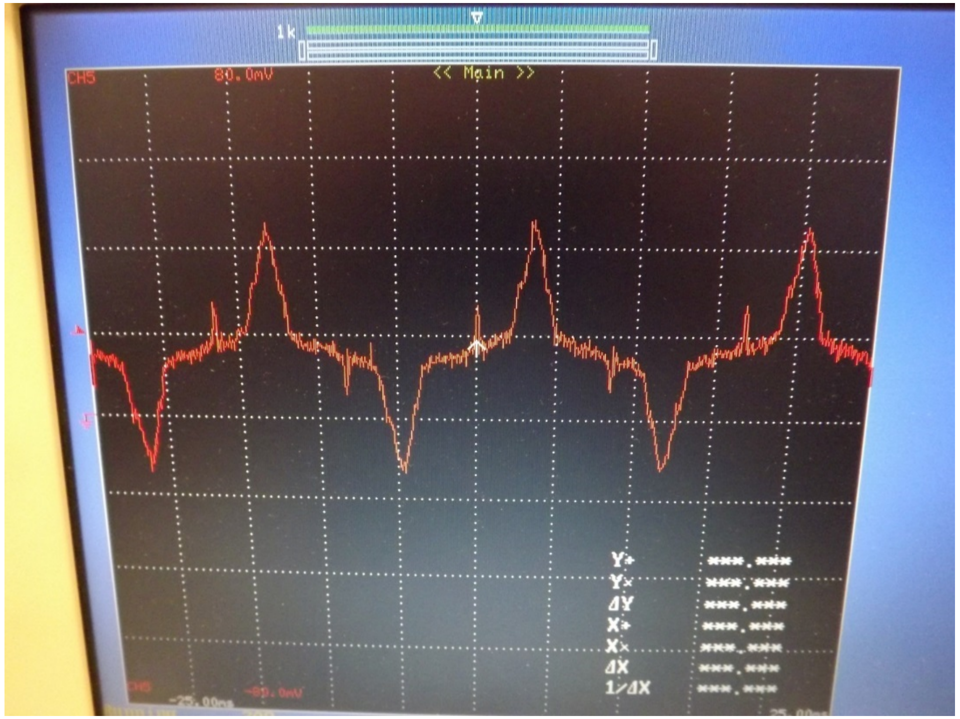
Incandescent Bulb
63.2 W, 1.0 PF



CFL Bulb
47.2 W, 0.59 PF



LED Bulb
10.4 W, 0.81 PF



Current waveform from non-dimmable LED bulbs used with a dimmer not rated for LED bulbs

Summary

- **Used integrated SG testbed for interoperability test specification drafts for PMUs, MUs, and Smart Sensors, including:**
  - **interoperability test methods**
  - **interoperability test suites and sets of test cases**
  - **interoperability test procedures**
- **Conducted interoperability tests on commercial devices**
- **Provided preliminary results of interoperability testingg**

Future plans:

- **conduct interoperability and performance tests on additional commercial MUs, PMUs, sensors, smart meters**
- **verify the interoperability and performance test methods,**
- **standardize interoperability test specifications for smart devices, and**
- **support standards development, interoperability and performance certification**

NIST Testbed Measurement Science April 26 2017

ISGT 2017: Innovative Research at the NIST Smart Grid Testbed

Universal CPS Environment for Federation (UCEF)

A Collaboration between NIST and Vanderbilt University

Presented by: Dr. Martin J. Burns

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Smart Grid and Cyber-Physical Systems Program Office

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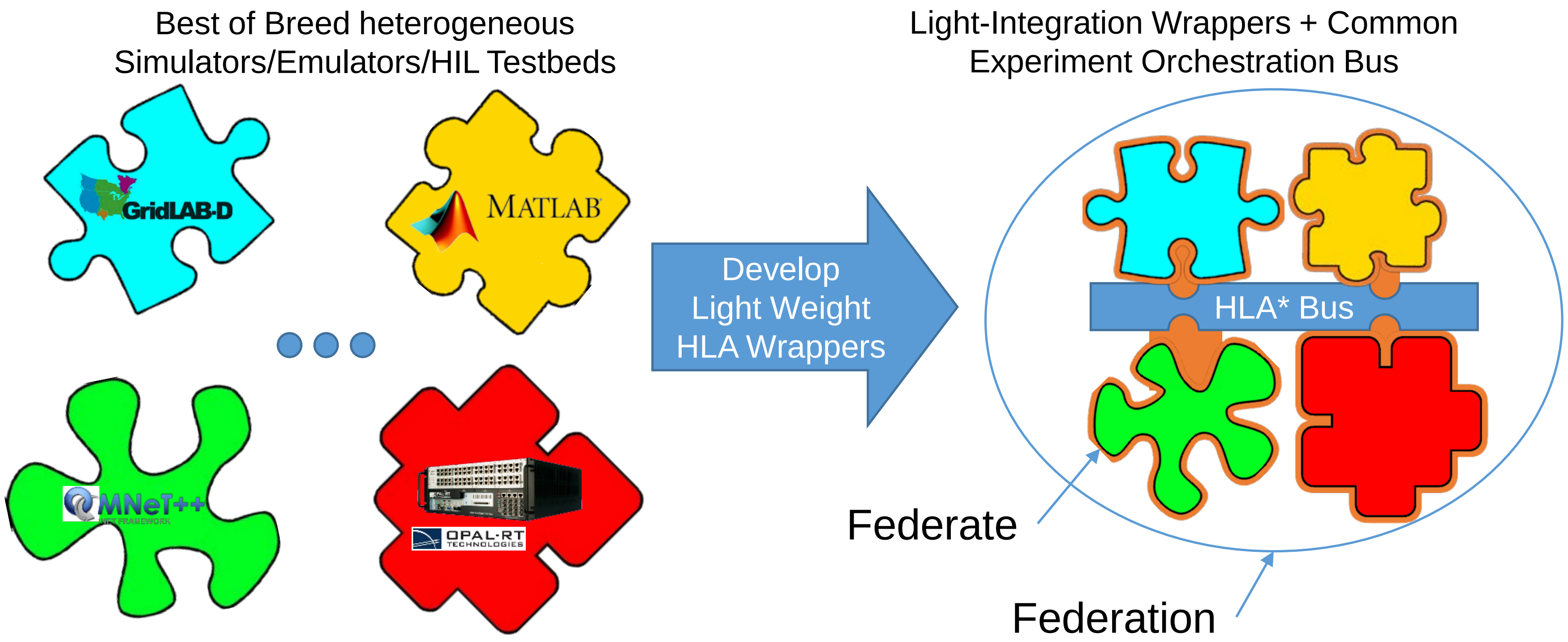
Why a Federated Testbed Architecture?

- What federation enables
  - Combine equipment that is unique or can’t be collocated
  - Proprietary components can be exposed by designed experiment interfaces
  - Creates reusable components of experiments
  - Integration of models from multiple domains
  - Our approach allows leveraging existing and disparate simulation tools and hardware in the loop and rapid experiment design and configuration
- Experimental Use Cases Enabled by UCEF
  - Local Experiment
  - Cloud Hosted Simulations and Experiments
  - Hardware In The Loop
  - Collaboration w/Remote Federates at other Labs
  - Large Scale Experiments (10s, 100s, 1000s of federates)
  - +++ Combinations of above

CPS Test Bed: Federation of Experiments

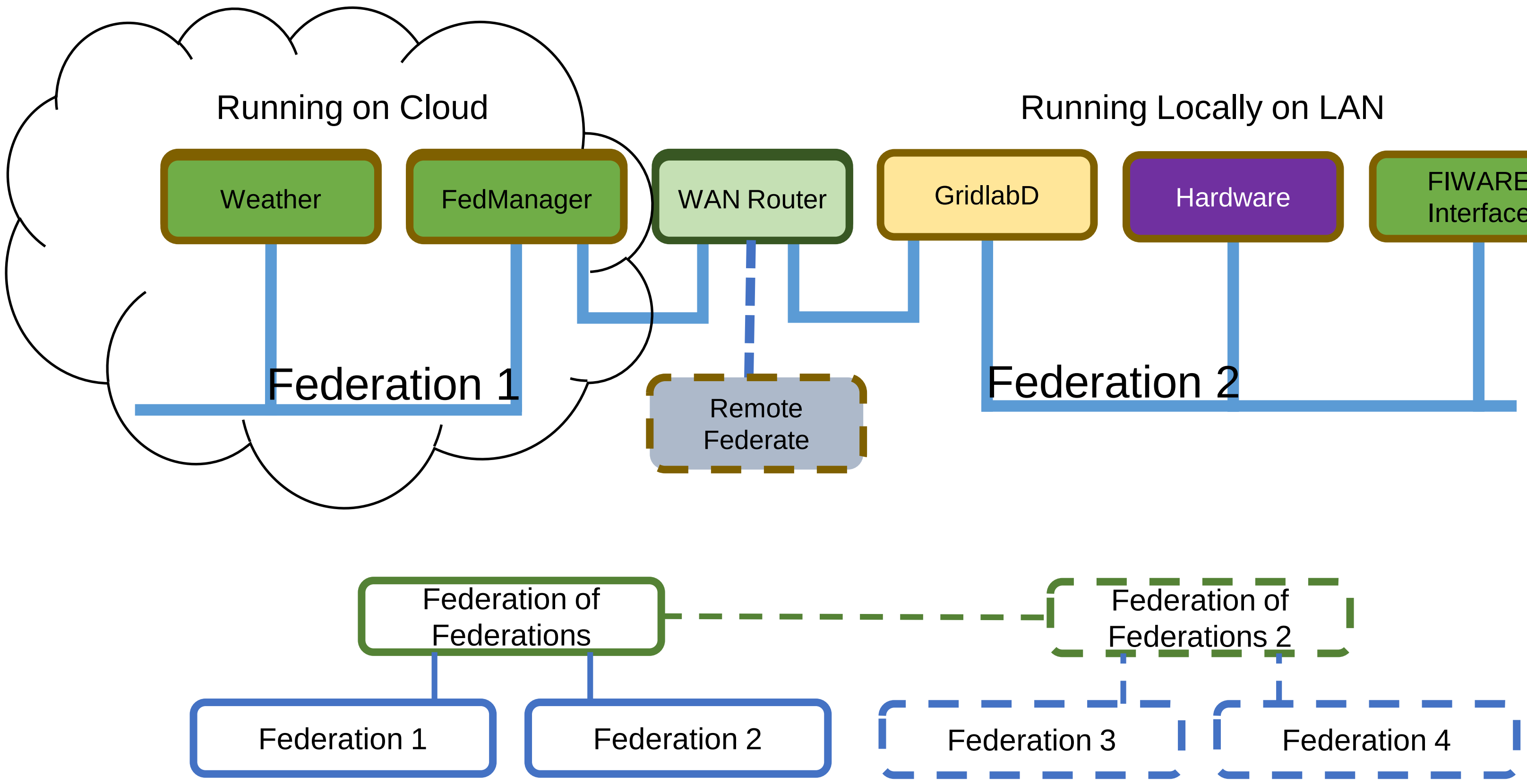
- Federated experiments allow components of experiments to be distributed locally, in clouds, and/or geographically dispersed.
- A Federate is a component of an experiment. It could be a piece of equipment, a simulation model, or a permutation of multiples of both….
- Federates can be located anywhere and are identified by their description and network address.
- A Federation is a collection of Federates that can be part of an experiment.
- An Experiment is the description of the orchestration of a Federation to exercise the Federates and exchange of information among them.
- The Federation Manager is a specialized Federate that operates on the Experiment definition and the Federation to perform the actual experiment.

Federation Concept

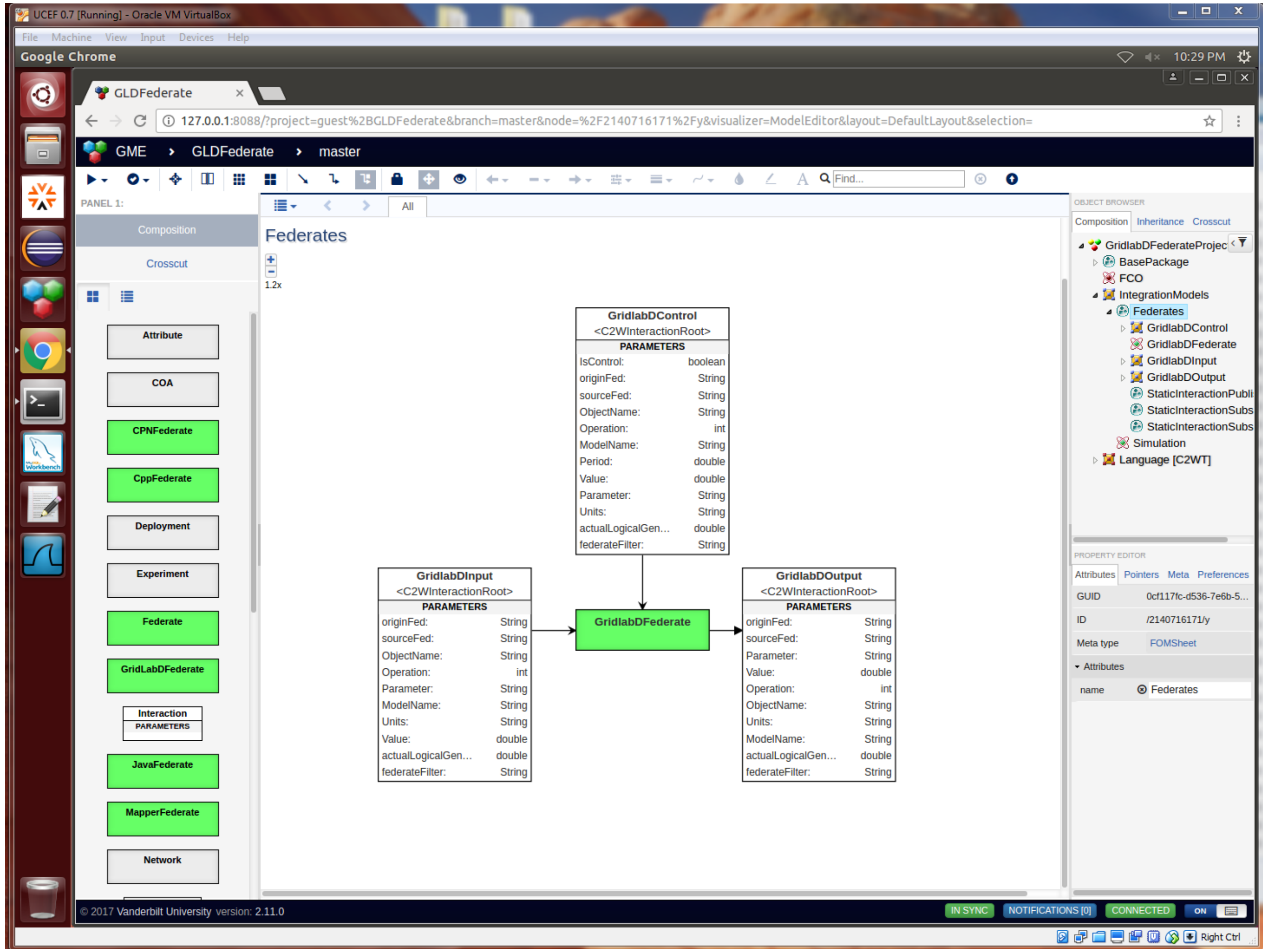


*https://standards.ieee.org/findstds/standard/1516-2010.html

Scalable and Composable



Universal CPS Environment for Federation Experiment Design Tool Suite



Federate Creation in 2 Minutes

Thanks, Questions?