EL Program: Smart Grid

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Strategic Goal: Smart Manufacturing and Cyber-Physical Systems

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Summary: This program develops and demonstrates smart grid measurement science advances to improve the system efficiency, reliability, resiliency, and sustainability of the nation's electric grid. In response to a mandate given by Congress and the Administration, NIST's Engineering Laboratory-led Smart Grid program leads the coordination and acceleration of smart grid interoperability and security standards in collaboration with the private sector, including the private-public non-profit organization Smart Grid Interoperability Panel 2.0, Inc. (SGIP), and through publication of the NIST Framework and Roadmap for Smart Grid Interoperability. By utilizing expertise in NIST's Engineering, Information Technology, and Physical Measurement Laboratories, this program advances the measurement science that will increase asset utilization and efficiency, improve grid reliability and resiliency, and enable greater use of renewable energy sources in the grid through research, standardization, testing and implementation of the NIST Framework.

DESCRIPTION

Program and Strategic Goal: The Smart Grid Program supports the objectives of the Smart Manufacturing, Construction, and Cyber-Physical Systems Strategic Goal to enable the next generation of innovative and competitive manufacturing, construction, and cyber-physical systems through advances in measurement science.

Objective: To develop and demonstrate advances in measurement science to enable integration of interoperable and secure real-time sensing, control, communications, information and power technologies, in order to increase the system efficiency, reliability, resiliency and sustainability of the nation's electric grid, by 2016.

What is the problem? In its present state, the electric grid is not capable of meeting the increasing demands of the 21st century economy for cost-effective, highly reliable, resilient and sustainable electric energy. It is estimated that on the order of $2 trillion worldwide will be needed to replace existing aging transmission, generation and distribution assets over the next 20 years. The national scale and importance of the problem and the drivers to modernize the nation's electrical grid through development of a smart grid are recognized in many policy documents, including the Energy Independence and Security Act of 2007 (EISA),[1] State of the Union addresses reiterating the President's vision for the clean energy economy,[2] the White House's "Blueprint for a Secure Energy Future,"[3] and the National Science and Technology Council (NSTC) reports "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future"[4] and "A Policy Framework for the 21st Century Grid: A Progress Report."[5]

Because the present system is designed to meet infrequent peak demands, it operates inefficiently, at roughly 50% system load factor on average. Improving system efficiency, reducing peak usage by managing demand as well as generation, and managing the system safely and reliably but closer to operational limits can optimize asset utilization and reduce investments that would otherwise be needed for business as usual scenarios. The reliability of the U.S. grid is an order of magnitude worse than that of some other developed countries such as Japan and Korea, imposing an estimated $80 billion to $100 billion in yearly economic losses to the U.S. economy.[6] Electricity generation accounts for 40% of human-caused CO_2 emissions, and renewable energy portfolio standards have been enacted in 29 states to drive more sustainable clean generation. The grid will have to be capable of more dynamic operation to support integration of significant amounts of intermittent renewable energy sources such as wind and solar, which are growing but still account for less than 5% of U.S. generation capacity. In addition, grid resiliency must be improved to restore operations quickly and systematically after wide-spread outages, such as due to severe weather and other events.

The overarching problem is that measurement science is lacking (1) to improve cross-cutting systems-level smart grid performance; (2) to enable real-time sensing and control of transmission and distribution grids; (3) to manage integration of new distributed energy resources throughout the grid; and (4) to fully integrate customer facilities with a smart grid. Integration of new sensor, communications, control and optimization technologies into the electric grid is critical to addressing these problems; however grid operators and regulators have been slow to adopt them at large scale because the measurement science to ensure expected benefits are realized is lacking. Technical barriers to their adoption include incomplete standards and testing programs for interoperability of smart grid devices and systems, concerns about cybersecurity and privacy, and lack of validated measurement methods and models that demonstrate that new smart grid technologies cost-effectively improve grid performance without introducing unforeseen instabilities and vulnerabilities.

Why is it hard to solve? The existing U.S. electric power grid is a complex and fragmented assembly of systems and operators, with complicated regulatory oversight and market structures governing a collective infrastructure investment of over $1 trillion. The grid is operated by approximately 3,200 electric utilities, delivering power to over 140 million customers, with equipment and systems provided by hundreds of suppliers, and many diverse stakeholder groups whose needs must be satisfied. In addition, with the absence of economical grid-scale electric storage, generation and consumption of electricity must be coordinated and balanced in real time, with large deviations causing blackouts and brownouts across regions of the grid.

Integrating new distributed intelligence, communications and control technologies and new operating paradigms in a large, complex system that must continue without interruption is a significant technical challenge, requiring robust, fully tested solutions based on interoperable and secure equipment and systems. Improving smart grid systems-level performance is hard because of lack of coordination and validation of integrated modeling of the multiple interconnected systems and subsystems, including at different time scales and abstraction levels together with significant physical and cybersecurity requirements. It is difficult to implement distributed sensing and control into transmissions and distribution grids because of the need to characterize the dynamic performance of equipment and sensors that are both cost-effective and operational under challenging field environments. It is hard to accommodate large amounts of intermittent distributed energy resources into the grid because the existing grids were not designed for two-way power flows, and required changes will substantially modify existing operations and safety procedures. A major paradigm shift for the grid is the automated management of demand as well as generation to optimize asset utilization and accommodate intermittent variable generation. The residential sector has little history of automation, and existing standards and control technology used in commercial and industrial facilities were not designed for interactions with a smart grid. In addition, significant technical challenges remain to model the bidirectional interactions between interacting subsystems and the smart grid in buildings and commercial and industrial facilities.

How is it solved today, and by whom? The challenging measurement science problems facing the smart grid have not been solved. Beyond NIST, smart grid research is conducted or supported by Department of Energy (DOE) and its National Laboratories, the National Science Foundation, utility suppliers, private institutes such as the Electric Power Research Institute, and academia. The DOE programs (including DOE-supported academic research) are focused mainly on technology development and demonstration projects. Industry R&D is mostly product-oriented. NIST's research is uniquely focused on measurement of grid devices and systems, protocols and standards for interoperability, and cybersecurity – for example, NIST's electrical metrology has supported the accuracy of individual grid elements such as electric meters and phasor measurement units. The NIST Framework and Roadmap for Smart Grid Interoperability Standards[7] is the primary reference for interoperability protocols and standards, not only for the U.S. but also internationally – it has been used by Japan, Korea, China and the EU in developing their own roadmaps. NIST's Guidelines for Smart Grid Cyber Security (NISTIR 7628)[8] is also cited internationally. While standards have been identified, many of them have not yet been validated through real-world performance. Few testing programs exist to ensure products and systems conform to standards, and are interoperable and secure. Validated system-level models do not yet exist to comprehensively predict, measure and optimize smart grid performance and build confidence that expected benefits will be realized.

Why NIST? Through EISA, NIST is charged with "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 …"[9] Having developed the NIST Framework and successfully engaged hundreds of private and public sector stakeholders by establishing the Smart Grid Interoperability Panel and encouraging its transition to the private-public nonprofit organization Smart Grid Interoperability Panel 2.0, Inc. (SGIP), NIST now has a unique opportunity to leverage the underlying capabilities in multiple Laboratories to advance the measurement science needs for the smart grid. This is consistent with the Engineering Laboratory (EL) strategic goal/objective to enable the next generation of innovative and competitive manufacturing, construction, and cyber-physical systems through advances in measurement science. Additionally, the Smart Grid program contributes to sustainable and energy efficient manufacturing, materials, and infrastructure, particularly through embedded intelligence in buildings and net-zero energy high performance buildings. The primary EL core competencies leveraged by the Smart Grid program are systems integration, engineering, and processes for cyber-physical systems and intelligent sensing, control, processes, and automation for cyber-physical systems, with additional support from the EL core competencies of energy efficient and intelligent operation of buildings with healthy indoor environments, and resilience and reliability of structures under multi-hazards (extended to infrastructures).

What is the new technical idea? The key technical idea is the development of a standards-based reference architecture, with associated interoperability and security requirements, as the foundation for prioritizing and addressing measurement science needs for the smart grid. This architectural framework is described in detail in the NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0 and Release 2.0, with draft Release 3.0 in preparation. By combining a focus on interoperability with traditional NIST expertise in measurement characterization, NIST will develop the necessary measurement science deliverables, including standards, protocols, models, test methods and research publications to ensure that the performance of the smart grid at the system, subsystem, and end-user levels can be measured, controlled, and optimized to meet interoperability, security, efficiency, reliability, resiliency and other performance requirements. To accomplish this, system-level standardized architectural concepts, data models and protocols integrated with new measurement methods and models will be characterized or developed to sense, control and optimize the smart grid's new operational paradigm. To improve transmission and distribution operations, the new technical idea is to develop the measurement science to support real-time monitoring of grid functions through multiple measurement/sensor network systems to produce actionable information for grid operators. New power electronics performance characterization will be developed to evaluate and integrate power conditioning systems with new functionalities to support distributed energy resources in the grid. For user-to-grid interactions, the approach will be to model the interaction of complex building systems with the grid in a holistic, integrated manner that considers system and consumer interactions and their impact on energy consumption, comfort, safety, and maintenance.

Why can we succeed now? Congressional and Administration mandates and continued support have provided a clear policy framework that ensures alignment of stakeholders on objectives to be achieved, coordination among federal, state and local government agencies, commitment and leverage of government and private sector resources, and regulatory support. They also have supported NIST to convene stakeholders in a collaborative process to develop solutions to measurement science problems, with extensive industry engagement and coordination. NIST leadership is globally recognized, and coordination activities with international partners provide key opportunities for the NIST effort to benefit from experience in smart grid development in other countries. Smart grid deployments are underway, including those supported by $4.5 billion of DOE smart grid investment and demonstration matching grants,[10] providing a source of real-world data for NIST measurement science research.

What is the research plan? The smart grid research plan consists of interrelated projects to advance measurement science to enable the implementation of new smart grid functionality that: improves grid reliability and resiliency; increases asset utilization and efficiency; and enables greater use of renewable energy sources in the grid. The projects are organized into five program thrust areas. These are: a systems-level cross-cutting Measurement Science for Smart Grid System Performance research thrust; three domain-focused research thrusts: Measurement Science for Transmission and Distribution Grid Operations; Measurement Science for Distributed Energy Resources and Microgrids; Measurement Science for User-to-Grid Interoperation; and the Smart Grid National Coordination function within the EL Smart Grid and Cyber-Physical Systems Program Office. The three domain thrusts develop enabling measurement science for robust sensing, power management and communications and intelligence within their domains, and the overarching system-level thrust supports system-level coordination, evaluation and use of these underlying domain capabilities under grid-scale operating conditions and addressing the cross-cutting security, network communications and electromagnetic environment. The Smart Grid National Coordination function continues its leadership role in engaging all key stakeholders in the smart grid community to ensure NIST smart grid program deliverables meet their needs. Below, each program area and its constituent projects are described including interrelationships, with additional detail and deliverables for individual projects provided within the associated project descriptions. With respect to safety, research performed within the different program areas is carried out under the safety policies and operations of the respective Laboratory with assigned responsibly for the physical laboratory space; relevant hazard review and other information is covered within the associated project descriptions.

Program Area: Measurement Science for Smart Grid System Performance

This thrust area includes five projects that provide the needed measurement science to support cross-cutting, systems-level analysis and operational needs. The projects' deliverables will enable actionable intelligence and decision-support modeling tools for grid-scale operators and provide the framework and tradeoff analyses for integration of domain-specific measurement science advances into overall grid operations, including addressing cybersecurity, understanding of network requirements, and acceptable performance within complex electromagnetic environments.

The Smart Grid Testing and Certification project develops the testing and certification framework for smart grid interoperability and ensures that the many different testing/certification efforts and directly associated standards are coordinated at the national and international level within the SGIP.

The Cybersecurity for Smart Grid Systems project leads the coordination of the SGIP Smart Grid Cybersecurity Committee and enables the development of industry standards and guidance to successfully implement secure Smart Grid technologies, with cybersecurity and privacy addressed throughout development cycles to avoid need to retrofit into products. To support the SGIP Catalog of Standards evaluations and gain information on current state of security within existing standards, a focus of FY14 efforts will be to review key standards against the requirements in the revised NIST Guidelines to Smart Grid Cyber Security (NISTIR 7628). Additional goals for FY14-FY15 are to use the new Advanced Metering Infrastructure (AMI) security testing framework to support development of new metering security requirements, and to evaluate smart grid cybersecurity within supply chain and cloud computing domains.

The Smart Grid Communication Networks project provides smart grid users with guidance and tools to help make informed decisions about smart grid communication network infrastructures. In FY14-FY15, this project will develop a co-simulation framework that captures high level interactions between the electrical and communications systems to identify performance gaps and vulnerabilities, and implement a distributed hierarchical network testbed to assess the suitability and expandability of synchrophasor IEEE C37.118 standards for communications in a hierarchical network structure. Networks rely on time synchronization capabilities, as addressed by the Precision Timing for Smart Grid Systems project, which will improve its IEEE 1588-based testbed and evaluate the impact of timing accuracy on control algorithms and estimation methods used in power systems, with particular focus on applications with fast dynamics including var (volt-ampere reactive) compensation, demand response, and regulation of distributed generation.

The Electromagnetic Compatibility of Smart Grid Devices and Systems project develops the measurement science including methodologies, guidance and standards to enable smart grid equipment and systems to function in a wide range of electromagnetic environments, and withstand electromagnetic events such as lightning strikes and other disturbances including the possibility of intentional attacks. Building on its SGIP Electromagnetic Interoperability Issues Working Group report assessing electromagnetic compatibility (EMC) in the smart grid, in FY14-FY15 the project will develop new smart grid EMC testing guidance, lead and contribute revisions of standards for priority concerns including smart meters (ANSI C12.1), and identify and address EMC issues for NIST smart grid testbeds currently under development.

The Smart Grid System Testbed Facility Project is creating a new integrated smart grid system measurement testbed that will provide NIST the technical capability to simulate advanced smart grid systems comprised of multiple heterogeneous subsystems and validate advanced modeling and analysis tools. When established, the testbed will become a focal point for internal coordination and collaboration among smart grid projects and for external collaborations with academia and industry. Initial renovation of the first labs was started in FY13, and initial equipment has been ordered. The initial scope of the testbed will include investigation of standards related to synchrophasor measurements and power conditioning systems. In FY14, the project will complete safety reviews and occupy and begin operations in the first labs of the smart grid testbed (power conditioning, synchrophasor, and cybersecurity), and in FY14-FY15 the project will develop and implement comprehensive plans for the testbed extension and combined operations.

Program Area: Measurement Science for Transmission and Distribution Grid Operations

This thrust area's two projects provide the measurement science to enable real-time situational awareness needed by grid operators. The projects' focus is to develop standards to support communication of actionable information from grid sensors, and new measurement methods to optimize the capabilities of these sensors to support grid operations. The Wide-area Monitoring and Control of Smart Grid project addresses measurement science and standards supporting deployment of Phasor Measurement Units (PMUs) and new Phasor Data Concentrators being deployed by utilities across the country in transmission grids. In FY14-FY15, the project will develop new test results and procedures to improve the performance and interoperability of commercial PMUs, optical, clamp-on and other smart grid sensors, and revise relevant standards and support adoption by industry. The Advanced Metering in Smart Distribution Grids project is focused on the measurement accuracy performance and role of smart meters as distributed end-node sensors in distribution grids. In FY14-FY15, the project will complete a testbed for high-accuracy testing of smart meters and, based on industry prioritization input, use it to develop meter test metrology for harmonic power and distorted waveforms characteristic of actual grid conditions. A key linkage with the Smart Grid Systems Performance thrust is that this new metrology development requires accurate characterization of the electromagnetic environments in which these meters must operate.

Program Area: Measurement Science for Distributed Energy Resources and Microgrids

In this thrust area, the Power Conditioning Systems for Renewables and Storage project addresses key measurement and standards barriers impeding deployment of distribution energy resources. In FY14-FY15, this project will develop the metrology and standards to characterize and integrate advanced power electronic conditioning systems (PCSs) with new functionalities (islanding, ridethrough/continued operation and other enhancements) needed to support the transformation to high penetration levels of PCS-based distributed generators, storage and microgrids. In addition to completing key standards revisions to the IEEE 1547 series and associated information exchange and test standards, the project will complete implementation of the core microgrid PCS lab of the smart grid testbed and will establish its baseline performance in FY14. In FY15, the testbed will be used to demonstrate interoperability test methods for smart grid-interactive functionalities of DER and microgrid interfaces and measurements of advanced smart grid PCS component technologies.

Program Area: Measurement Science for User-to-Grid Interoperation

In this thrust area, the Building Integration with Smart Grid project is developing underpinning measurement science necessary to integrate customer facilities with a smart grid, through development of high impact industry standards, industry-run testing and certification processes to support implementations, and new industry best practices. This includes improving and expanding consumer access to their energy usage information in the White House Green Button Initiative, for which NIST has made significant technical contributions to improve the consistency of available data and industry implementations, and will continue to drive progress with sponsorship of a White House Presidential Innovation Fellow starting in June 2013. In addition to Green Button implementation activities, in FY14 the Building Integration with the Smart Grid project will continue standards development activities that support key standards for building-to-grid integration identified in the NIST Smart Grid Roadmap. In FY14-FY15, the project will also conduct research expected to result in new control strategies for managing electrical loads and local generation that can pioneer a new era of real-time electricity pricing, increased use of renewable energy sources, and building electrical load management that is responsive to needs of the smart grid.

Program Area: Smart Grid National Coordination

The Smart Grid National Coordination function within EL's Smart Grid and Cyber-Physical Systems Program Office carries out NIST's statutory responsibility to coordinate standards development for smart grid interoperability and provides programmatic leadership of NIST smart grid measurement science research in the Engineering Laboratory, the Information Technology Laboratory, and the Physical Measurement Laboratory. The National Coordination function provides national and global leadership to the smart grid community and liaises with Congress, the Executive Office of the President, DOE, FERC, state regulators, and other government agencies. It leads the development and public review process for the NIST Framework and Roadmap for Smart Grid Interoperability Standards (Draft Release 3.0 currently in preparation). It also provides leadership within the new private-public nonprofit organization, Smart Grid Interoperability Panel 2.0, Inc. (SGIP) and oversees the new NIST-SGIP cooperative agreement, and administers the Smart Grid (Federal) Advisory Committee. EISA directs NIST to submit a report to Congress on the smart grid as NIST deems appropriate; in FY14 a report will be developed on the NIST smart grid interoperability framework, covering accomplishments in development of standards for the smart grid, progress in deployment, and remaining challenges in measurement science supporting smart grid interoperability and cybersecurity. In FY14-FY15, a key focus will be to augment Office staff and program capabilities by developing new smart grid measurement science efforts to address challenging standards needs and research barriers, including efforts with potential extension to other cyber-physical systems. Initial efforts have included establishing a cooperative agreement with a leading university in smart grid systems research, which will support longer-term development of a measurement science program in smart grid modeling and simulation.

How will teamwork be ensured? With leadership and program coordination from the EL Smart Grid and Cyber-Physical Systems Program Office, the smart grid program relies on contributions from approximately 20 NIST staff members in Engineering Laboratory, Physical Measurement Laboratory, and the Information Technology Laboratory. Weekly smart grid team meetings ensure coordination and communication, and provide a mechanism to raise and address the variety of measurement science and standards issues. Reviews of all projects within the program have been held this year to provide input for management prioritization and program evolution. The integrated smart grid testbed under development will provide an additional mechanism to foster collaborative research teamwork.

ACCOMPLISHMENTS and IMPACT

R&D Impact:

The Smart Grid Program includes research and development efforts within its projects that achieve impact through peer-reviewed archival journal publications. These activities and impacts are anticipated to increase in future years as the Program continues to identify, establish and implement research capabilities to address smart grid measurement challenges in key priority areas, including in its smart grid testbed and in smart grid systems modeling and simulation.

- **Top Journals:** Within the smart grid field, the top journals for communicating research advances are published by the Institute of Electrical and Electronics Engineers (IEEE). Based on relevance and potential for impact, six IEEE Transactions journals are identified below as leading publications for the Smart Grid Program in the future, along with their respective impact factors (2011). Two journals are new publications, and impact factors are not yet available. An additional journal (Proceedings of the IEEE) is identified based on two Smart Grid Program publications in 2011 in a special publication edition. Additional journals may be also appropriate for communicating Smart Grid Program research results, given the interdisciplinary breadth of smart grid research in areas such as electrical power metrology, power electronics, building controls, communications, electromagnetic compatibility and cybersecurity. For program evaluation and tracking purposes, the average impact factor is proposed to be used for all journals; the choice of journal for publishing will be determined by project, based primarily on programmatic alignment with established journal audiences, with lesser consideration based on impact factor.

  IEEE Transactions on Smart Grid: Impact factor not available (new)
  IEEE Transactions on Power Electronics: Impact factor 4.560
  IEEE Transactions on Power Systems: Impact factor 2.678
  IEEE Transactions on Wireless Communications: Impact factor 2.586
  IEEE Journal on Selected Areas in Communications, Series on Smart Grid Communications: Impact factor not available (new)
  IEEE Transactions on Electromagnetic Compatibility: Impact factor 1.178
  [Proceedings of the IEEE: Impact factor 6.810]

- **Research Outcomes:** A list of ERB-approved papers submitted for publication in the identified list of peer-reviewed, archival journals in 2012-2013 is provided below, along with project name(s) in brackets:

- “On Statistical Modeling and Forecasting of Energy Usage in Smart Grid,” W. Yu, D. An, D. Griffith, Q. Yang, and G. Xu, submitted to *IEEE Transactions on Smart Grid* [Smart Grid Communication Networks, FY13]
- “Guest Editorial – Smart Grid Communications,” N. Golmie, A. Scaglione, L. Lumpe, E. Yeh, Lang Tong, and Sean Smith, submitted to *IEEE Journal on Selected Areas in Communications* [Smart Grid Communication Networks, FY13]

A few additional ERB-approved papers submitted for publications in other journals are listed below for reference:

- Calibration of Phasor Measurement Units at NIST,” Yi-Hua Tang, G.N. Stenbakken, and A. Goldstein, submitted to *IEEE Transactions on Instrumentation and Measurement* [Wide-area Monitoring and Control of Smart Grid, FY13]
- “'4-Way Handshaking Protection for Wireless Mesh Network Security in Smart Grid,” H. Gharavi and B. Hu, submitted to *IEEE GLOBECOM 2013*. [Smart Grid Communication Networks, FY13]
- “Adaptive Key Management for Wireless Sensor Networks,” T. Cheneau and M. Ranganatha, submitted to *IEEE GLOBECOM 2013*. [Smart Grid Communication Networks, FY13]
- “Frameworks and Data Initiatives for Smart Grid and other Cyber-Physical Systems” D.A. Wollman, submitted to *Proceedings of the 7th International ACM Conference on Distributed Event-Based Systems* [Smart Grid National Coordination: Smart Grid Secretariat, FY13]

- **Potential Research Impacts:** The first paper listed has been accepted for publication in the identified list of peer-reviewed, archival journals in 2012-2013, and below are listed two publications in other peer-reviewed journals, along with project name(s) in brackets and fiscal year of acceptance:
  - “Guest Editorial – Smart Grid Communications,” N. Golmie, A. Scaglione, L. Lumpe, and E. Yeh, IEEE Journal on Selected Areas in Communications (June 2012) 30 (6) 1025-1026. [Smart Grid Communication Networks, FY12]
  - “Testing phasor measurement units using IEEE 1588 precision time protocol” Julien Amelot and Gerard Stenbakken, *Proceedings of IEEE Precision Electromagnetic Measurements*, July 2012. [Precision Timing for Smart Grid Systems, and Wide-area Monitoring and Control of Smart Grid, FY12]
  - “Traffic Scheduling Technique for Smart Grid Advanced Metering Applications,” H. Gharavi and C. Xu, *IEEE Transactions on Communications* (June 2012) 60 (6) 1646-1658. [Smart Grid Communication Networks, FY12]

- **Realized Research Impacts:** A list of published papers in peer-reviewed, archival journals is provided below, along with project name(s) in brackets, fiscal year of acceptance and number of citations (as of May 2013):
  - “Multigate Communication Network for Smart Grid” Hamid Gharavi and Bin Hu, *Proceedings of the IEEE* (June 2011) 99 (6) 1028-1045. [Smart Grid Communication Networks, FY11, 11 citations]
  - “Smart Grid: The Electric Energy System of the Future” Hamid Gharavi and Reza Ghafurian, *Proceedings of the IEEE* (June 2011) 99 (6) 917-921. [Smart Grid Communication Networks, FY11, 8 citations]

- "An IEEE 1588 time synchronization testbed for assessing power distribution requirements" Julien Amelot, Jeffrey Fletcher, Dhananjay Anand, Clement Vasseur, Ya-Shian Li-Baboud, and James Moyne. *Proceedings of the IEEE Symposium on Precision Clock Synchronization* (October 2010) 13-18.
  [Precision Timing for Smart Grid Systems, FY11, 10 citations]
- "A practical implementation of distributed system control over an asynchronous Ethernet network using time-stamped data" Dhananjay Anand, Jeffrey Fletcher, Ya-Shian Li-Baboud, and James Moyne. *Proceedings of the IEEE Conference on Automation Science and Engineering* (August 2010) 515-520.
  [Precision Timing for Smart Grid Systems, FY10, 7 citations]

Impact of Standards and Tools: The Smart Grid Program has strong engagement with end users and delivers significant impact through technology transfer including development and use of multiple standards and tools. NIST smart grid team members have accelerated standards development to fill numerous identified standards gaps by leading specific standardization efforts within multiple standards development organizations and by leading higher-level smart grid standards coordination activities. Included in tools provided by NIST are guidance and technical documents including NIST Special Publications (NIST SPs) such as the NIST Framework and NIST Interagency Reports (NISTIRs). Additional tools provided by NIST include software support tools, and establishment and operations of the leading private-public partnership for smart grid coordination, the Smart Grid Interoperability Panel 2.0, Inc. (SGIP). The NIST-SGIP memorandum of understanding, cooperative agreement and working relationships provide multiple mechanisms to support NIST interactions with industry and knowledge transfer. These include NIST leadership within the SGIP committees and domain expert working groups, NIST leadership of SGIP priority action plans, specific NIST contributions to SGIP work products, and active, visible participation in SGIP workshops. Knowledge transfer is also accomplished through direct outreach to key groups such as state regulators (individually and through the National Association of Regulatory Utility Commissioners), testing and certification organizations, and trade associations. Other mechanisms of knowledge transfer include leadership and participation in additional conferences and workshops, technical publications, and project-focused collaborative work with industrial and academic partners.

Given the extensive portfolio of technology transfer activities of the Smart Grid Program, several groups of key outcomes and impacts are described below.

- **Technology Transfer Outcomes:** Below are select standards or tools drafted and/or made available publicly that have potential to achieve broad-based end-use.

    - Standards supporting demand response, pricing and energy management have been developed through NIST and SGIP effort and are now available and have high likelihood of use. [Building Integration with Smart Grid, FY13]

        - The OpenADR 2.0 standard has been drafted and is nearing completion. This standard represents an implementation of a subset of OASIS Energy Interop (EI) features that specifically relate to demand response (OpenADR refers to Open Automated Demand Response). Demand response in Open ADR 2.0 can be triggered by either price signals or by requests to shed load based on a set of levels. OpenADR 2.0 is a refinement on a previous version that has been used in many field trials in the U.S. and several other countries. It is supported by an industry alliance (OpenADR Alliance) that is beginning interoperability testing of the revised version. Interoperability testing is a necessary first step towards broader implementation. (FY13)

    - Smart Energy Profile (SEP) 2.0 has been recently completed and published by the Zigbee Alliance. SEP2.0 is a key standard identified in the NIST framework, covering residential consumer energy communications with devices. (FY13)

- Several standards in the IEEE 1547 family and UL1741 have been developed and published, forming a technical foundation to support increased utilization of smart grid-interactive distributed energy resources (DER), and increased use of these standards is anticipated. Public rulemaking proceedings are also being conducted by FERC, the California Public Utility Commission and others referencing the need for the new functionalities of these standards. [Power Conditioning Systems for Renewables, Storage, and Microgrids, FY11-FY13]

    - IEEE 1547.4 for grid islanding applications and IEEE 1547.6 for secondary networking were published. (FY11)
    - UL 1741 Certification Requirements Document (CRD) "Special Purpose Utility Interactive Product Requirements" was published. (FY13)
    - IEEE P1547.8 for advanced grid-interactive DER functionalities is on track for publication this year. (FY13)
    - IEEE 1547a (Amendment 1 to IEEE 1547) is on track for publication this year, with modifications to address voltage regulation and frequency ride-through based on new functionalities needed to support interconnection of distributed energy resources. (FY13)
    - IEC 61850-7-420 new edition is on track for publication in FY13 including the multifunctional electric storage, distributed energy resources operational interface of IEC 61850-90-7 (published this year) and harmonization and mapping with other standards. (FY13)

- With NIST leadership, the SGIP Electromagnetic Interoperability Issues Working Group published its SGIP white paper titled "Electromagnetic Compatibility and Smart Grid Interoperability Issues." The paper looks at EMC issues and standards in a variety of different environments—both within the electric utility system and within power customer settings—and provides guidance for applying documented EMC principles to better ensure the operation and interoperability of the smart grid in its intended electromagnetic (EM) environments. This culmination of an extensive EMC analysis and standards review is likely to have significant use and impact to motivate the revision of several smart grid standards including the ANSI C12.1 standard for smart meters.

[Electromagnetic Compatibility of Smart Grid Devices and Systems, FY13]

- NIST published two R&D measurement needs reports from an August 2012 workshop attended by 90 leading technical and industry experts in the smart grid community. The reports, titled "Strategic R&D Opportunities for the Smart Grid" and "Technology, Measurement, and Standards Challenges for the Smart Grid" identify some of the most important technical issues in the smart grid field, and prioritize impediments and R&D areas that must be addressed for successful deployment of the smart grid. The workshop was a collaborative effort of NIST and the Renewable and Sustainable Energy Institute (RASEI), a joint institute of the University of Colorado Boulder and the National Renewable Energy Laboratory (NREL). [Smart Grid National Coordination: Smart Grid Measurement Science Program Development and Management, FY13]

- NIST published its Draft NISTIR 7823 Advanced Metering Infrastructure Smart Meter Upgradeability Test Framework. The Draft NISTIR 7823 proposes an example test framework and conformance test requirements for the firmware upgradeability process for the Advanced Metering Infrastructure (AMI) Smart Meters. The conformance test requirements in the Draft NISTIR 7823 are derived from the National Electrical Manufacturers Association (NEMA) Requirements for Smart Meter Upgradeability standard, which defines requirements for Smart Meter firmware upgradeability in the context of an AMI system for industry stakeholders such as regulators, utilities, and vendors. Draft NISTIR 7823 identifies test procedures that the vendors and testers can voluntarily use to demonstrate a system's conformance with the NEMA standard.
  [Cybersecurity for Smart Grid Systems, FY12-FY13]

- A suite of tools (Precision Time Protocol Testbed, Dashboard, and Conformance Test Plan) has been developed by NIST and the University of New Hampshire to enable industry to assess the timing performance of precision time protocol equipment and provide an increased level of assurance in IEEE 1588 implementation performance and interoperability for power grid applications. The testbed incorporates several hardware and software measurement tools to measure timing precision between many devices. The open-source dashboard has been developed and transferred to the University of New Hampshire for development of conformance tests. A conformance test plan for IEEE C37.238: IEEE Standard Profile for Use of IEEE 1588 Precision Time Protocol in Power System Applications has been drafted and will be published as a NISTIR with review by the IEEE Power Systems and Relay Committee.
  [Precision Timing for Smart Grid Systems, FY12-FY13]

- **Potential Technology Transfer Impacts:** Examples of standards/tools with dissemination and adoption with the potential to achieve significant broad-based end use for the smart grid include:

- With NIST leadership, several Phasor Measurement Unit (PMU) standards were developed over several years on an accelerated timeline and are being adopted to support interoperability and accurate testing of over 1000 new PMUs being installed with DOE American Recovery and Reinvestment Act funding. NIST support, including development of the original steady state tests and new dynamic tests, was critical to the establishment of these standards and their continued evolution. [Wide-area Monitoring and Control of Smart Grid, FY10-FY13]

  - IEEE C37.242-2013, a guide for the synchronization, calibration and installation of PMUs, was accelerated with NIST support, and is based in large part on NIST research. It supports the accelerated timeline for ARRA-funded deployments of PMUs. (FY13)
  - IEEE C37.244-2013, a guide for phasor data concentrators (PDCs) was accelerated with NIST support, and is based on NIST research. It supports the accelerated timeline for ARRA-funded deployment of PMUs and PDCs. (FY13)
  - IEC 61850-90-5 Edition 1.0 integrates the IEEE C37.118.1 data with the IEC 61850 standard. It was coordinated as part of under the NIST-led SGIP Priority Action Plan 13 and is now being implemented in ARRA-funded PMUs. This 61850 standard offers much greater functionality, flexibility, and interoperability than the original IEEE C37.118-2005 standard. (FY12)
  - IEEE1815-2012 is a standard for electric power systems communications using the Distributed Network Protocol (DNP3). It was accelerated under the NIST-led SGIP Priority Action Plan 12, and is a revision of IEEE 1815-2010 that adopts improved cybersecurity as recommended by the NIST-led SGIP cybersecurity review of the earlier standard. It is a step toward making legacy grid control systems interoperable with advanced control systems based on IEC 61850. (FY12)
  - IEEE C37.118.1-2011 covers performance requirements and testing for PMUs, and incorporates tests developed by NIST for PMU performance under dynamically changing conditions. (FY11)
  - IEEE C37.238-2011 is a guide for precision clock synchronization for electric power grid applications. It was coordinated as part of the NIST-led SGIP Priority Action Plan 13 and enables precision time synchronization among devices in substations for improved grid reliability and resilience. (FY11)
  - IEEE C37.239-2010 provides a common format for anomalous event data exchange in the grid. It was coordinated as part of the NIST-led SGIP Priority Action Plan 14 and was developed to improve interoperability of various wide-area monitoring devices and systems. (FY10)
  - IEEE1815-2010 is a standard for electric power systems communications using the Distributed Network Protocol (DNP3). It was accelerated under the NIST-led SGIP Priority Action Plan 12, and is an IEEE adoption of a widely used standard developed by the DNP users group for substation monitoring and control. It is a first step toward making legacy grid control systems interoperable with advanced control systems based on IEC 61850

for improved grid reliability and resilience. (FY10)

- Phasor Measurement Units (PMU) synchrometrology laboratory, measurement service, and test tools. NIST was the first National Metrology Institute to offer traceability for PMUs through a special test calibration service, enabling vendors to verify compliance with standards and receive detailed NIST feedback to improve their products' performance. In support of this test capability, NIST installed a new three-phase PMU calibrator developed under a NIST ARRA grant in FY13, and is conducting dynamic testing according to IEEE C37.118.1-2011 for 6 commercial PMUs, with testing of a new IEC 61850-90-5-compliant PMU scheduled to begin in June 2013. The automation provided by the PMU calibrator greatly reduces the turnaround time for reporting test results to the manufacturers and accelerates product improvements. The NIST synchrometrology work has led to a suite of tests that have been adopted in IEEE and IEC standards, and the NIST-developed PMU test tools (hardware and software) have now been adopted by a commercial test laboratory, Quanta Technology. The NIST lab has also developed signal processing models for calculation of synchrophasors compliant with the IEEE standards to compare with commercially-developed models to demonstrate the validity of PMU standards and identify gaps to be addressed for improved performance and reliability. [Wide-area Monitoring and Control of Smart Grid, FY11-FY13]

- NISTIR 7761 "Guidelines for Assessing Wireless Standards for Smart Grid Applications" (PAP02 on Wireless Communications), published in February 2011, has provided stakeholders with a method and tools for quantifying smart grid applications communication requirements. Anecdotal evidence indicates that several utilities and network equipment vendors have used it in their requests for proposals and product development. An updated version NISTIR 7761V2 will be published in FY14. [Smart Grid Communications Networks, FY11]

- The OASIS Energy Market Information Exchange (EMIX) and Energy Interoperation (EI) standards have been published and are in use, with potential to achieve significant broad-based end use in the future. EMIX defines an information model representing price and product information intended to serve as the basis for communication protocol standards that will exchange this information. EI builds on the product information from EMIX and specifies an information model and messages that enable standard communications of: demand response events, electricity prices, market participation bids and offers, and load and generation predictions. [Building Integration with Smart Grid, FY12]

- Green Button Standards. With NIST leadership and SGIP priority action plan support, NAESB Energy Usage Information REQ-18/WEQ-19 and Energy Services Provider Interface (ESPI) REQ-21 standards have been published and provide the foundation for the Green Button Initiative to enable consumers to more readily access their own energy usage information in a standardized electronic format. Additionally, NAESB Third Party Access to Smart Meter-Based Information REQ-22 is being utilized in these efforts to better protect customers' privacy. Based on first adopter electric utility implementations, over 19 million U.S. customers now

have Green Button Download My Data access, and a few utilities have implemented pilot Green Button Connect My Data programs. Based on additional utility commitments, the program will grow to include over 30 million customers in 2013, indicating significant potential for wide-spread use.
[Building Integration with Smart Grid, FY12-FY13]

  - Green Button Software Development Kit. As described in a February 2013 NIST Techbeat article,[11] NIST has contributed tools to support Green Button implementations and testing and certification programs, as well as web tools (www.greenbuttondata.org) to enable self-testing of the structure of Green Button files. Multiple utilities and vendors have committed to the Green Button initiative and are using NIST Green Button tools to support their implementations. With additional NIST technical support, EPA implemented an upgrade of its Home Energy Yardstick residential evaluation tool to be able to upload Green Button data. [Building Integration with Smart Grid, FY13]

  - Interoperability Process Reference Manual (IPRM) Version 2.0. With NIST leadership, the SGIP Testing and Certification Committee has finalized and published a revised version of the framework for testing and certifying Smart Grid products. This updated version of the IPRM provides information, guidelines and best practices for test programs and guidance and recommendations for test laboratories and certification bodies. Several organizations, including OpenADR, UCAIug, MultiSpeak, NEMA, USNAP and the SEP2 Interop Consortium have made commitments to and/or are in the process of implementing test programs based on the IPRM. [Smart Grid Testing and Certification, FY11-FY13]

- **Realized Technology Transfer Impacts:** Selected examples of tools in use with significant, broad-based end-use for the smart grid realized include:

  - NIST Framework: The NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0 (and Release 1.0), NIST Special Publication 1108R2 (and 1108) is the primary reference document for interoperability protocols and standards, not only for the U.S. but also internationally. It has been used by Japan, Korea, China and the EU in developing their roadmaps, and by utilities and vendors as overall guidance to support interoperability of systems and devices. The NIST Smart Grid Program is currently working on an update of the NIST Framework; after public review in late 2013, a final Release 3.0 of the NIST Framework is anticipated to be published in early 2014.
[Smart Grid National Coordination: Smart Grid Secretariat, FY10-FY13]

  - NISTIR 7628 Guidelines for Cyber Security (Volumes 1, 2, and 3) publication has achieved wide recognition and use for utilities, vendors, and regulators, and is also cited internationally. With input from the SGIP Smart Grid Cybersecurity Committee, NIST has completed and posted the first draft of (revised) NISTIR 7628 Guidelines for Smart Grid Cyber Security, Revision 1 for SGCC review and comment, with an additional public comment period planned before a final version is published. [Cybersecurity for Smart Grid Systems, FY09-FY13]

  - Smart Grid Interoperability Panel (SGIP) 1.0 and SGIP 2.0, Inc. and associated outputs including the Catalog of Standards. The public-private partnership SGIP 1.0 (established by NIST in November 2009) and subsequent private-public partnership nonprofit organization SGIP 2.0, Inc. (established in 2012, operational in April 2013) have become the leading national and international smart grid organizations to visibly align and coordinate smart grid stakeholders to accelerate smart grid standardization and deployment. NIST has worked with the SGIP as a primary mechanism to obtain "input and cooperation" with the private sector and other agencies in developing the NIST smart grid interoperability framework. With over 190 member organizations (as of May 2013), industry is now contributing membership dues of over $1,000,000, representing greater than 50% of funding for SGIP 2.0 operations, consistent with increased industry leadership and its identification as a private-public partnership. The SGIP's Catalog of Standards (CoS) is considered to be the "Physician's Desk Reference" of smart grid standards to support industry implementations, and is one of many SGIP outputs that provides significant value to the smart grid community. Based on its consensus-confirming voting process and supported by technical reviews of standards, the CoS includes 56 standards (as of May 2013) voted for inclusion by the SGIP plenary membership. [Smart Grid National Coordination, FY10-FY13]

- **Other**: The Smart Grid Program uses a variety of additional mechanisms to disseminate knowledge and results to identified end-users, including its website and newsletter. These have been effective, with positive feedback from utilities (one asked permission and distributed a copy of the website content to its state regulatory commission) and other stakeholders. Additional media outreach, webinars, and invited speaking roles have resulted in significant positive media coverage as described below.
[Smart Grid National Coordination: Smart Grid Secretariat, FY12-FY13]

Recognition of EL: The Smart Grid Program has received awards and other recognition, as described below.

External awards:
Grid Week Advisory Board "Taming Complexity" award to the NIST Smart Grid Interoperability (October 2012)

Grid Week Advisory Board "Smart Policy" award to the Green Button Initiative (October 2012)

DOC/NIST awards:
2011 Gold Medal for NIST smart grid team members, for developing a globally-recognized smart grid standards framework enabling transition to a clean energy economy and increased U.S. competitiveness.

2012 Bronze Medal for Ya-Shian Li-Baboud, for development of a time synchronization conformance and interoperability test bed to assure compliance to critical requirements of the Smart Grid.

2012 Bronze Medal for Thomas Nelson, for leadership in helping to ensure the reliability of the emerging Smart Grid through establishing the world's first synchrometrology test bed.

Stakeholder recognition:
NIST SG Federal Advisory Committee report, March 2012
"NIST's work to establish Smart Grid interoperability protocols and standards has been carried out both methodically and with a sense of urgency, and NIST is to again be commended for the enormous task it has undertaken and for its many accomplishments over the last two and a half years"

Federal Energy Regulatory Commission, July 2011
"We believe that the best vehicle for developing smart grid interoperability standards is the NIST interoperability framework process, including the work of the SGIP and its committees and working groups…The Commission recognizes and appreciates the comprehensiveness of the smart grid interoperability framework process developed by NIST… we encourage utilities, smart grid product manufacturers, regulators, and other smart grid stakeholders to actively participate in the NIST interoperability framework process to work on the development of interoperability standards and to refer to that process for guidance on smart grid standards"

National Association of Regulatory Utility Commissioners, July 2011
"When evaluating smart grid investments, State commissions should consider how certified smart grid interoperability standards may reduce the cost and improve the performance of smart grid projects and encourage participation in the Smart Grid Interoperability Panel, a public-private partnership that is coordinating and accelerating the development of interoperability standards for the smart grid."

Positive media coverage:
An example of stakeholder recognition in the media includes a recent article titled "Standards, Net Metering, and a New Energy Culture" in Electric Light & Power, Jan-Feb 2013.
"...NIST formed the Smart Grid Interoperability Panel (SGIP) from stakeholders and experts. The goals of SGIP were and are to identify the types of standards needed, to enlist participants and standards-setting organizations to create them, and to do this in a short time.
It's working. … The key was NIST's conceptual framework, which caused members to focus on bite-sized chunks, real-world cases and early involvement of standards. NIST also announced SGIP 2.0, which formalizes this process with an independent public-private partnership. "

In addition, the Smart Grid Program has received substantial positive media coverage, available internally through NIST News Clips dissemination. A few examples include:

"Patrick Gallagher: National Institute of Standards and Technology Director" Main Justice, May 2013, coverage included statement "NIST … developed a standards framework for a national computer-based electrical grid under the Energy Independence and Security Act. The agency’s successful development of the “Smart Grid” led to its being named as a key developer of Obama’s flagship cyber initiative.”

“SGIP to receive $2.75 million, continued expertise from NIST” Smart Grid Today, April 2013, coverage of cooperative agreement between NIST and SGIP 2.0.

“NIST Targets Energy Apps with Green Button Tools” InformationWeek, February 2013, coverage of new User Guide to NIST Green Button Software Development Kit.

“Connecting buildings to the Smart Grid - Engineers should know the NIST and ASHRAE standards for the Smart Grid, and be aware of the availability of Smart Grid-ready products for commercial buildings.” Consulting-Specifying Engineer, December 2012, coverage of several NIST smart grid standardization efforts.

[1] Energy Independence and Security Act of 2007 [Public Law No: 110-140], available at http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf

[2] The White House, Office of the Press Secretary, "Remarks by the President in State of the Union Address." January 25, 2011, January 24, 2012, and February 12, 2013. See http://www.whitehouse.gov/the-press-office/2011/01/25/remarks-president-state-union-address and http://www.whitehouse.gov/the-press-office/2012/01/24/remarks-president-state-union-address and http://www.whitehouse.gov/the-press-office/2013/02/12/remarks-president-state-union-address

[3] The White House, "Blueprint for a Secure Energy Future." March 30, 2011, available at http://www.whitehouse.gov/sites/default/files/blueprint_secure_energy_future.pdf

[4] National Science and Technology Council, "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future." Available at http://www.whitehouse.gov/sites/default/files/microsites/ostp/nstc-smart-grid-june2011.pdf

[5] National Science and Technology Council, "A Policy Framework for The 21st Century Grid: A Progress Report." Available at http://www.whitehouse.gov/sites/default/files/microsites/ostp/2013_nstc_grid.pdf

[6] Understanding the Cost of Power Interruptions to U.S. Electricity Consumers, LBNL-55718, available at http://certs.lbl.gov/pdf/55718.pdf

[7] NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0 and Release 2.0, available at http://www.nist.gov/smartgrid/upload/FinalSGDoc2010019-corr010411-2.pdf and http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf

[8] NISTIR 7628 Guidelines for Smart Grid Cyber Security, available at http://www.nist.gov/smartgrid/upload/nistir-7628_total.pdf

[9] Energy Independence and Security Act of 2007 [Public Law No: 110-140], Sec. 1305, available at http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf

[10] Department of Energy, Electric Delivery and Energy Reliability Office, "Economic Impact of Recovery Act Investment Grant and Smart Grid Demonstration Projects as of March 2012." Available at http://energy.gov/sites/prod/files/2013/04/f0/Smart%20Grid%20Economic%20Impact%20Report%20-%20April%202013.pdf

[11] "New Guide Will Allow Electric Utilities to Develop Green Button Web Tools," NIST Tech Beat (February 6, 2013), available at http://www.nist.gov/el/button-020613.cfm