A High Performance Secure Platform for Smart Grid Research - the Internet2 Network

28 September 2015

The Internet2 Collaborative Innovation Initiative

Foreword

This paper describes one of several exploratory activities currently in progress as part of the Internet2 Collaborative Innovation Initiative[1]. The overall initiative is led by Florence Hudson, Senior VP and Chief Innovation Officer for Internet2. This initiative incorporates many topics being explored by initiative participants, including end to end trust and security, distributed big data and analytics, and the Internet of Things. The Smart Grid concepts described in what follows include aspects of each of these areas.

This Smart Grid exploration is a work in progress. This document was developed by Robert Brammer, Senior Advisor to the Internet2 CEO, with inputs from initiative participants. It describes our current vision and approach. However, it is likely that there will be changes for the remainder of this year while the Internet2 management and membership decides how to proceed with this and other possible new initiatives.

For further information about the Internet2 Collaborative Innovation Initiative and this Smart Grid exploration contact:

Florence Hudson
Senior VP and Chief Innovation Officer
Internet2
fhudson@internet2.edu

[1] http://meetings.internet2.edu/media/medialibrary/2015/04/29/20150429-Hudson-Collaborative_Innovation.pdf

A High Performance Secure Platform for Smart Grid Research -- The Internet2 Network
28 September 2015

Executive Summary

This paper addresses researchers interested in the Smart Grid. In particular, we address researchers at Internet2 member institutions who may not yet be aware of the potential resources in the Internet2 community that can aid in the development of large-scale multi-institutional collaborative research with significant advantages in performance, functionality, security, and cost-effectiveness.

The Smart Grid markets have grown rapidly and will continue do so during the next decade, driven by needs for decreased costs, reduced carbon emissions, increased grid security and reliability, and more electric power. Realizing the benefits of the Smart Grid requires significant advances in information technology and systems to collect, secure, manage, analyze, and act on massive volumes of information. These advances will help to meet these needs and will enable significant advances in grid intelligence. There is a high requirement for reliability of the grid and associated information flows, as well as increasing needs to mitigate risks from physical and cyber-attacks on the grid. Many reports address such requirements. For example, last year the Center for the Study of the Presidency and the Congress developed a report for the President entitled, "Securing the U.S. Electrical Grid." Furthermore, research in distributed operations are important. For example, NIST organized a workshop focused on Smart Grid testbeds. The resulting NIST report devotes considerable discussion to the benefits and challenges associated with networked testbeds.

Internet2 has a unique position in the Research and Education (R&E) community with a history of facilitating unique and innovative member-led initiatives. Internet2 has created the world's most powerful research network with current optical capacity of 8.8 terabits per second (soon to double) across the US. This network connects members of the US research and education community with unmatched capabilities for high performance and minimal latency. Of particular interest to Smart Grid researchers are the Advanced Layers 1 and 2 services. These services enable researchers to create custom high performance networks with the flexibility, security, and privacy to meet their needs. Internet2's Advanced Layer 1 Service enables researchers to create a state-of-the-art network isolated from the public Internet with more access points than any other national R&E network. Internet2's Advanced Layer 2 Service provides effective and efficient wide area 100 gigabit Ethernet technology. This service is used today by researchers needing big data and secure network services. This service enables balancing long-term or short-term global big data science collaborations and production services, as well as research on network capabilities. Additionally, Internet2 has begun a discussion with the NERC about jointly developing the needed guidelines and regulatory frameworks. Consistent with the Internet2 mission, work on our network will be for research and education, including advanced concept development and feasibility tests where no operational risks arise. However, we want to do this research and education in a realistic environment.

Many of our member institutions have researchers who are already engaged in Smart Grid research and operational activities. However, all of these current and potential Smart Grid researchers may not be fully aware of Internet2's activities and resources in areas such as trust and security, software-defined networking, IPv6, federated identity, and others. Consequently, we believe that there are significant opportunities to extend Smart Grid research using Internet2 resources, notably in areas using Smart Grid Testbeds. Consequently, Internet2 is planning to develop a testbed environment to help enable Smart Grid research, notably in areas of networked microgrids and institutional testbeds.

These ideas are discussed further in this paper with footnotes providing references to provide further information for research. In particular, we provide further information about Internet2. We invite your inquiry.

A High Performance Secure Platform for Smart Grid Research -- The Internet2 Network
25 September 2015

Introduction

As stated in the Executive Summary, our focus is on communicating the potential of Internet2[2] resources to Smart Grid[3] researchers so that they can extend the depth and breadth of their research[4]. The ideas described here are part of a Collaborative Innovation Initiative at Internet2 and to an Internet2 outreach effort to a broader population of researchers whose work can leverage and benefit from new developments in advanced networking, high performance computing (HPC), big data, end to end trust and security, and other priorities in this community.

Smart Grid Background

Driven by needs for decreased costs, reduced carbon emissions, increased grid security and reliability, and more electric power, the global markets for Smart Grid systems and technology has grown rapidly and will continue to do so during the next decade[5]. Many industry analysts have observed how our aging and technically obsolete grid are threatening reliability standards and causing needless environmental impact. Moreover, new types of loads from distributed operations and DC devices are challenging the current AC grid architecture. Necessary changes will require significant investment. For example, the Edison Electric Institute estimates that "By 2030, the electric utility industry will need to make a total infrastructure investment of $1.5 trillion to $2.0 trillion."[6] This figure includes additional intelligence and direct electrical infrastructure upgrades and replacements.

Realizing the benefits of the Smart Grid will require significant advances in relevant information technology and systems to collect, secure, manage, analyze, and act on the massive volumes of relevant information. These advances will help to meet the above needs and will enable significant advances in relevant grid intelligence.[7] For example, some early research suggests that smart grid data may be comparable in size to that of the multi-petascale social networks and also has aspects that require high speed transmission with synchronization and minimal latency.[8] Accordingly, Smart Grid data management is a growing distributed big data problem with critical timing and security requirements that will require many new developments to realize practical and timely benefits.

Moreover, since there is a high requirement for reliability of the grid itself and associated information flows, more diverse grid interfaces, increased consumer participation, as well as an increasing need to mitigate

---

[2] www.internet2.edu

[3] In this paper, we use the somewhat colloquial term "Smart Grid" as a short version of the very broad term "21st Century Grid Technologies." Our intent with this concise term is to capture the potential for significant integration of information and communication technologies into the future power grid.

[4] While we do mention some research sponsors, this is not a guide to Smart Grid research funding programs. We believe that researchers are familiar with these sponsors and have other information sources about their programs.

[5] Bennet A. and Fike, V., US Department of Commerce, "The Global Grid-Smart Grid Growth in International Markets, US Government Support for Exporters," Electric Light & Power, 16 January 2015

[6] The Edison Electric Institute, "Transforming Americas Power Industry," http://www.eei.org

[7] Venayagamoorthy GK, "Dynamic, Stochastic, Computational and Scalable Technologies for Smart Grid", *IEEE Computational Intelligence Magazine* (*Special Issue on Smart Grid*), Vol. 6, No. 3, August 2011, pp. 22-35.

[8] Aiello, A., and Pagani, G., "The Smart Grid's Data Generating Potentials," Proceedings of the 2014 Federated Conference on Computer Science and Information Systems pp. 9–16

risks from physical and cyber-attacks on the grid[9], there is a growing need for grid modernization. In particular, there is a strongly growing need for regional and national situational awareness of grid status.[10] For example, last year the Center for the Study of the Presidency and the Congress developed a report for the President entitled, "Securing the U.S. Electrical Grid."[11] This reports notes that the President has directed the Executive Branch to "Develop a situational awareness capability that addresses both physical and cyber aspects of how infrastructure is functioning in near-real time."[12] The report presents a dozen recommendations, including the following

> *"Unresolved questions about the implementation of Smart Grid, microgrid, and the shift to renewable generation require further examination with an eye towards grid security and reliability."*

In addition to federal attention to the need for improved situational awareness for the power grid, there is considerable industry interest. Many power industry analysts have been discussing the integration of information technology and operational technology (IT/OT)[13], and this type of integration in the power grid (e.g., integrating IP and SCADA networks) is a prime example. This type of integration leads to new requirements for situational awareness. For example, the presentation[14] on grid real-time monitoring and analysis given in a June 2015 North American Electric Reliability Corporation (NERC) Technical Conference provides considerable data on the motivation and requirements for creating grid situational awareness. An informal group, the North American Synchrophasor Initiative, is doing related work.[15] Many utilities have related developments within their operating areas.[16]

The Internet2 Consortium

The Internet2 Consortium is a highly innovative community with unique resources that could be used to help to develop regional and national-level Smart Grid situational awareness capabilities and to enable examination of advanced technologies that may be proposed for use in such developments. The Internet2 membership of nearly 500 institutions includes all of the leading US research universities, many leading corporations developing relevant technologies and systems, regional and state education networks across the US, and many engaged federal agencies (including the DOE laboratories, NIST, and NSF). Additionally, we have partnerships with research and education networks in more than 100 countries. Consequently, there is considerable opportunity for multi-institutional collaboration facilitated by the Internet2 Consortium and a nearly 20 year history of such collaboration.

Internet2 created the world's most powerful research network with current optical capacity of 8.8 terabits per second (soon to double) across the US. This network connects members of the US research and education community with unmatched capabilities for high performance and minimal latency. The network offers many services, including wide area petascale file transfer and a selection of distributed collaboration services, including video conferencing and telepresence. Furthermore, since Internet2 is a leader in software defined

---

[9] The Department of Energy has begun to adapt the NIST Cybersecurity Framework to Smart Grid requirements. See the DOE report, "Energy Sector Cybersecurity Framework Implementation Guidance", January 2015

[10] Beasley C, Zhong X, Deng J, Brooks R, Venayagamoorthy GK, "A Survey of Electric Power Synchrophasor Network Cyber Security", *IEEE PES Innovative Smart Grid Technologies Conference*, Istanbul, Turkey, October 12-15, 2014.

[11] McLarty III, T. and Ridge, T., "Securing the U.S. Electrical Grid," The Center for the Study of the Presidency and Congress, Washington DC, July 2014

[12] Presidential Policy Directive 21, "Critical Infrastructure Security and Resilience," February 2013

[13] Steenstrup, K. and Iyengar, P., "2016 Strategic Roadmap for IT/OT Alignment," Gartner, Inc. G00277331, June 2015

[14] NERC, "Project 2009-02, Real-Time Monitoring and Analysis Capabilities," Technical Conference, 4 June 2015

[15] www.naspi.org

[16] Rahman, T., et al, "Real time Situational Awareness of WAMS at San Diego Gas and Electric," 16 March 2014

networking, the network has the flexibility to adapt segment architectures to meet a variety of requirements.[17] It is exactly the platform for the "High-bandwidth, low-latency, cost-effective, interoperable communications systems will that will overlay the future grid"[18] called for in many Smart Grid planning reports. While the network-related focus here is on the use of the Internet2 network, we emphasize the close working relationships with the Energy Sciences Network[19] (ESnet) connecting the US DOE labs, and the various regional and state educational networks. They may be interested in some form of collaboration here and will be included in future discussion.

Of particular interest to Smart Grid researchers are the Internet2 Advanced Layer 1 and 2 services[20]. These services enable researchers to create custom high performance networks with the flexibility, security, and privacy to meet their needs. Internet2's Advanced Layer 1 Service enables researchers to create a state-of-the-art network isolated from the public Internet with more access points than any other national R&E network, including paths through regions never served before. Internet2's national fiber network, optical system and network operations center (NOC) provide a set of leading edge resources and capabilities that offers the most reliable, high-capacity network solution. While Internet2 continues to implement advanced security features (e.g., custom tools for monitoring networks at these high performance bandwidths), the high degree of reliability and security in this flexible research platform can be augmented by further research projects to address the particular requirements of the Smart Grid. Internet2's Advanced Layer 2 Service provides effective and efficient wide area 100 gigabit Ethernet technology. This service is being used today by researchers needing big data capabilities (e.g., particle physics data from the Large Hadron Collider) and secure network services (e.g., genomic and other biomedical data). The flexibility of this service enables balancing long-term or short-term global big data science collaborations and production services, as well as research on network capabilities (e.g., researchers on the GENI program).

Internet2 has a unique position in the Research and Education (R&E) community[21] with a history of facilitating unique and innovative member-led initiatives in advanced networking, federated identity management, and cloud services. The Internet2 network, the InCommon Federation, and the NET+ Program and other Internet2 member developments show the benefits to the broader R&E community from collaboration facilitated by Internet2.

Smart Grid Research

Many of our member institutions have researchers who are already engaged in Smart Grid research and operational activities. For example, nearly all of the Smart Grid research projects listed by the National Renewable Energy Laboratory for their Climate-Neutral Campus Program[22] are funded at Internet2 member institutions. Furthermore, some of our university members have significant campus projects. For example, Cornell University and Washington State University have a joint project called GridControl[23] for grid monitoring and control. Clemson University's situational intelligence (SI) laboratory is able to collect, analyze and predict synchrophasor data/information[24]. Additionally, the University of Pittsburgh's Center for Energy manages the DC-

[17] Ramel, D., "Internet2 Achieves SDN-Enabled Milestone: Virtualization Review", November 2014
[18] Grid Wise Alliance, "The Future of the Grid," National Summit, 26 June 2014, p7
[19] https://www.es.net/
[20] For further information on these services -- http://www.internet2.edu/products-services/advanced-networking/
[21] The term "R&E community" as used here includes higher education institutions, corporate R&D organizations, and government agencies with strong interest in advanced information and communications technology.
[22] http://www.nrel.gov/tech_deployment/climate_neutral/smart_grid.html
[23] http://www.cs.cornell.edu/projects/gridcontrol/
[24] "Real-Time Power and Intelligent Systems Laboratory" – http://rtpis.org.

AMPS Program (Direct Current Architecture for Modern Power Systems) for DC-based power electronics technologies. This team will be building a High-Voltage/High-Power Lab at the Pittsburgh Energy Innovation Center and is working with Internet2 to explore options for campus-I2 connectivity.

Personnel from Internet2 industry member institutions have participated in some larger Smart Grid projects, including the Pacific Northwest Smart Grid Demonstration Project and the European Union Smart Grid Demonstration Project. Additionally, Internet2 members (e.g., IBM, GE) are also working with several major utilities on Smart Grid projects.

However, all of these current and potential Smart Grid researchers may not be fully aware of Internet2's activities and resources in areas such as trust and security, software-defined networking, IPv6, federated identity, and others. Consequently, we believe that there are significant opportunities to extend Smart Grid research using Internet2 resources, notably in areas using Smart Grid Testbeds.

Smart Grid Testbeds

In December 2014, NIST published a report on a workshop focused on Smart Grid testbeds.[25] The report devotes considerable discussion to the benefits and challenges associated with networked testbeds. In particular, one of the key findings of the workshop is the following

> *"Significant measurement, characterization, performance, and other challenges remain that will benefit greatly from testbed analysis and demonstration. A range of testbed scenarios are needed, including 1) targeted testbeds for unique problems; 2) modular/composable testbeds; and 3) <u>interconnected testbeds – across domains, with multiple interconnected smart grid technologies, and those that connect the different capabilities of R&D laboratories or organizations</u>." (Emphasis added.)*

The report also provides a set of interconnected testbed priorities which the Internet2 services could help to address. Appendix A in that report lists more than 30 Smart Grid testbeds, and more than half of them are operated by Internet2 member institutions. Consequently, there is a considerable facilities base to leverage, and the use of the Internet2 network could help to address some challenges noted in the report about shared infrastructure. However, the report does not mention "grid situational awareness" or "the Internet2 network," so some of the ideas described here will complement the developments described in that report.

We have reviewed these projects and many others and believe that we can extend Smart Grid research with the advanced networking capabilities of the Internet2 network. What could be created beyond current activities are pilot distributed situational awareness projects that could demonstrate advanced concepts and technologies for the Smart Grid in distributed multi-institutional collaborations. These projects, enabled by the unique capabilities of the Internet2 network, could show results scaling above current demonstrations. For example, they could show how the integration of such diverse data types as grid phasor measurement unit (PMU) data[26], weather information[27], cyber threat information[28], and power grid generation and load demand data[29] could be used to enhance decision making and emergency response to significant grid incidents. Issues that could be addressed include the management of PMU data from 1000's of units[30], prediction of grid vulnerabilities

[25] NIST, "Measurement Challenges and Opportunities for Developing Smart Grid Testbeds," December 2014
[26] https://www.naspi.org See also the EPRI Research Program that Includes NASPI sponsorship. www.epri.com
[27] http://www.weather.gov The National Weather Service provides ready access to large volumes of data
[28] There are several commercial cyber threat information services, as well as industry ISACs creating relevant data
[29] Data from regional Independent System Operators (ISOs) can be made available with proper arrangements
[30] NASPI, "Synchrophasor Technology Fact Sheet, 2014

during extreme weather conditions[31], response of the grid and management centers to simulated cyber-attacks[32], and the factors necessary to facilitate distributed collaboration[33] among diverse governing organizations involved in grid decision-making in critical situations. On-demand HPC to do forecasting of grid state during an emergency would also be possible with the aforementioned facilities.

Through successful research based on ideas described here, the government could develop a national view of the real-time transmission system, similar to what the FAA has for the National Airspace System, fed from the regional independent system operators (ISOs). This could provide the timely detection and decision making that was not possible, for example, during the August 2003 US northeast blackout and could address the national objectives stated above for real-time situational awareness and decision making for the grid during emergencies.

Unique Security and Operational Policy Challenges

The National Energy Reliability Corporation (NERC)[34] is responsible for publishing guidelines laying out the security expectations that power system operators must follow. Called the NERC Critical Infrastructure Protection guidelines, NERC CIP[35] (currently at version 5.0) dictates the specific rules concerning physical infrastructure protection, vetting employees who would have physical access, logical security policies and monitoring obligations, and data encryption standards that should be used. The NERC CIP rules were conceived when utilities typically operated their own dedicated communications infrastructures. Thus, there are significant legal obstacles to simply using the NERC CIP rules in applications that might use Internet links supplied by third parties. This stands as a non-trivial barrier to adoption of the standard Internet model by major smart grid operators, who would face stiff penalties for violating the NERC CIP even in unintentional ways.

As a part of this Smart Grid initiative, Internet2 has begun a discussion with the NERC about jointly developing the needed guidelines and regulatory frameworks. Consistent with the Internet2 mission, work on our network will be for research and education, including advanced concept development and feasibility tests where no operational risks arise. However, we want to do this research and education in a realistic environment. Hence participation by the Internet2 community in creating NERC guidelines aimed at leased private network structures, similar to the Internet2 network, would be important in accelerating the research results into operations. Such steps would advance a national cause in many ways. We can help to further the transformation of the US power grid so as to achieve the benefits discussed earlier. We can do this in ways that are secure against tampering, that minimize vulnerability to third-party errors such as network configuration mistakes, and also that are unbiased with respect to particular characteristics of major smart grid participants. Research in these aspects would also be important to accelerate the development of the Smart Grid.

Concluding Remarks and Next Steps

Initial pilot projects focused on research related to grid situational awareness on a large regional or national scale could build on our existing network infrastructure and member capabilities to minimize cost and time to show significant results. While this paper has focused on Smart Grid applications and the implications of the regulatory environment, notably large-scale situational awareness, it is clear that the Internet2 assets

---

[31] Abi-Samra, et al, “Managing Extreme Weather Events Affecting Electrical Power Grids,” IEEE Power and Energy Society, September 2014
[32] McLarty op cit,
[33] Cisco, “Collaboration Case Studies,” www.cisco.com
[34] http://www.nerc.com/Pages/default.aspx
[35] http://www.nerc.com/pa/Stand/Pages/CIPStandards.aspx

described above could be applied more generally to other areas including other aspects of Smarter Cities and Smarter Campus initiatives.

We are reaching out to many diverse stakeholders to determine how best to proceed with these ideas. Specifically, we will be discussing these ideas further in the Internet2 Collaborative Innovation Initiative meetings and at the Technology Exchange meeting in October 2015.[36] If there is sufficient interest, we may organize a workshop to develop these ideas further. If all of this is successful in attracting and organizing a critical mass of qualified and interested researchers, our vision is to obtain the resources to develop a national-level program and platform for Smart Grid research with emphasis on the essential grid situational awareness capabilities envisioned by the President's direction. We invite your feedback at CINO@internet2.edu

---

[36] https://meetings.internet2.edu/2015-technology-exchange/