U.S. Department of Energy
Office of Electricity Delivery & Energy Reliability

Smart Grid Research & Development

Multi-Year Program Plan (MYPP)

2010-2014

September 2012 Update

Acknowledgment

This Multi-Year Program Plan (MYPP) for the Smart Grid Research & Development Program within the U.S. Department of Energy (DOE), Office of Electricity Delivery & Energy Reliability, is the second annual update of the 2010 edition that was produced with significant input and contributions from the MYPP Working Groups and various stakeholders who attended the Smart Grid R&D Roundtable Meeting on December 9-10, 2009. This update incorporates further stakeholder input from the Smart Grid R&D Discussion Forum held in June 2012 and the DOE Microgrid Workshop in July 2012. The DOE also acknowledges the efforts of Energy & Environmental Resources Group, LLC, (E2RG) in facilitating and preparing this annual update of the MYPP.

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Executive Summary

The Smart Grid Research and Development (R&D) Program within the Research and Development Office of the U.S. Department of Energy (DOE) Office of Electricity Delivery & Energy Reliability (OE), in accordance with Title XIII of the Energy Independence and Security Act of 2007 (EISA), is tasked with accelerating the deployment and integration of advanced communication, control, and information technologies that are needed to modernize the nation's electric delivery network. The R&D effort described in this second update of the Multi-Year Program Plan (MYPP)[1] is foundational in advancing both the underlying science and the technology required to realize smart grid capabilities and benefits.

The vision of the Smart Grid R&D Program is that:
By 2030, the power grid has evolved into an intelligent energy delivery system that supports plug-and-play integration of dispatchable and intermittent low-carbon energy sources, and provides a platform for consumer engagement in load management, national energy independence, innovation, entrepreneurship, and economic security. This smart grid supports the best and most secure electric services available in the world and connects everyone to abundant, affordable, high quality, environmentally conscious, efficient, and reliable electric power.

The OE defines the smart grid by seven characteristics or principal functionalities: 1) customer participation, 2) integration of all generation and storage options, 3) new markets and operations, 4) power quality for the 21st Century, 5) asset optimization and operational efficiency, 6) self healing from disturbances, and 7) resiliency against attacks and disasters. These functionalities will lead to achieving the Smart Grid R&D Program's 2020 goals of developing commercially viable microgrids, developing a self-healing electric distribution grid, and enabling high penetration of distributed energy resources (DER),[2] demand response (DR), and plug-in electric vehicles (PEVs) in distribution grid, as shown in Figure A.

The 2020 goals of the Smart Grid R&D Program support:

- The 2010 OE Strategic Goals: Develop market-deployable advanced electric transmission and distribution (T&D) technologies and facilitate expansion of our Nation's electricity infrastructure capacity; and Identify, prioritize, coordinate, and improve the protection and restorative capability of national and international critical energy infrastructure assets and key resources;

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[1] The Smart Grid R&D Multi-Year Program Plan (MYPP) was first published in May 2010, and had its first annual update in September 2011 (available at http://energy.gov/oe/downloads/smart-grid-rd-multi-year-program-plan-2010-2014-september-2011-update).

[2] Distributed energy resources include distributed renewables (photovoltaic and wind) and distributed generation (microturbines, reciprocating engines, Stirling engines, fuel cells, and combined heat and power systems).

- The Secretary's Goal of Energy: Build a competitive, low-carbon economy and secure America's energy future; and
- The President's targets of 80% of America's electricity from clean energy sources by 2035 and 1 million electric vehicles (EVs) on U.S. roads by 2015.

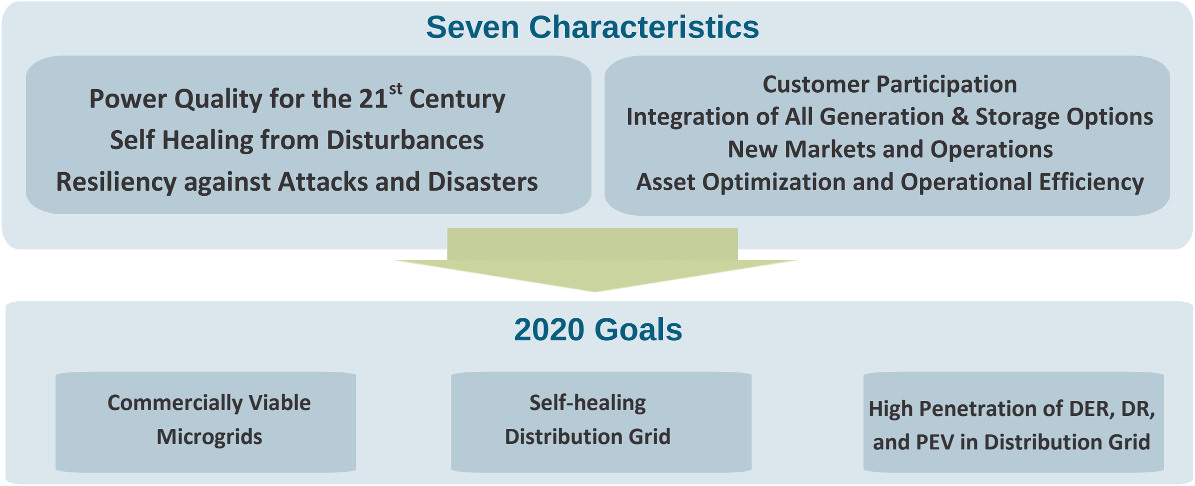

Figure A. Supporting Relationships between Smart Grid Characteristics and Smart Grid R&D Program's 2020 Goals

The portfolio of Smart Grid R&D Program activities will primarily focus on distribution systems and consumer devices, including interfaces and integration with transmission and generation systems. The R&D areas are organized into the following five topics:

1. Standards & Best Practices
2. Technology Development
3. Modeling
4. Analysis
5. Evaluation & Demonstrations

Each R&D topical area is summarized below, with details provided in section 3 of this MYPP.

Standards & Best Practices

Standards & best practices are needed for electrical and communications interconnection, integration, interoperability, conformance test procedures, and operating practices. R&D is directly in support of the National Institute of Standards and Technology (NIST) Smart Grid Interoperability Standards Program including development and testing of the Institute of Electrical and Electronics Engineers (IEEE) P2030 Series of Smart Grid Interoperability Standards and IEEE 1547 Series of Interconnection Standards, as well as development and dissemination of smart grid interoperability related methods, tools, and education. R&D activities will focus on:

- Developing, maintaining, and harmonizing national and international standards on interconnection, integration, interoperability, and cyber security requirements and conformance test procedures for distributed energy resources.
- Developing and maintaining legacy and advanced distribution system protection, operations, and automation best practices.

Technology Development

Technology development encompasses advanced sensing and measurement, integrated communications and security, advanced components and subsystems, advanced control methods and system topologies, and decision and operations support. R&D is occurring primarily in four sub-areas: integration of DER and DR to reduce peak load and improve system efficiency; smart charging of PEVs; microgrids development to meet reliability and energy security requirements of commercial and military applications; and advanced communications and controls to achieve distributed intelligence beyond distribution substations. R&D activities will focus on:

- Microgrids development for energy security to critical loads.
- Protection and control technologies that work safely, efficiently, and reliably in the presence of high-penetration DER and changing network conditions.
- Advanced sensing and measurement to support faster and more accurate response such as remote monitoring and demand-side management.
- Distribution automation to reduce system outage duration and frequency.
- Grid-to-vehicle and vehicle-to-grid technologies, e.g., intelligent control of PEV charging.

Modeling

This topic area includes accurately modeling the behavior, performance, and cost of distribution-level smart grid assets and their impacts at all levels of grid operations from generation to transmission and distribution. R&D includes: development of integrated distribution management systems for distribution system planning, operations, and control; and development of an agent-based, multi-disciplinary tool (GridLAB-D™) to simulate the effects and benefits of smart grid technologies on an integrated T&D system. R&D activities will focus on:

- Modeling of integrated power system with communications network for the effects of latency, traffic volumes, availability and integrity of data (data dropouts), and communication media on power system planning, operations, and reliability.
- Development, testing, and validation of advanced control algorithms in different modeling and simulation platforms for varying time scales.
- Modeling for improved representation of renewable resources on the distribution system, including real and reactive power modeling for inverter-based equipment, resources forecasting, generation profiles, temporal and spatial representation of environmental events such as cloud passage, and protection impacts such as variations in fault current.
- Interoperability among data that drives models; interoperability of model components among models; and integration of formerly independent (disparate) models.
- Test cases for availability of measured data for model verification and validation (V&V) and modeling load profiles.

Analysis

Analysis of measured data and simulations is needed to better understand the impacts and benefits concerning high penetration levels of intermittent renewable resources and DR, various charging scenarios for PEVs, microgrid development for its designed objectives (economic, reliability, environmental, and security), and consumer energy and cost savings, as well as economic/business environment and crosscutting goals. R&D activities will focus on:

- Assessing the progress of Recovery Act smart grid investments. Ensuring that sufficient data are collected to support analyses, as well as effective access and use of collected data. Researching appropriate mechanisms to manage and coordinate such large datasets with existing and emerging datasets related to smart grid, such as those gathered through international efforts and the Smart Grid Information Clearinghouse project. Common standards and formats for data are required.
- Understanding the issues and potential remedies to support effective cyber security, information privacy, and interoperability practices and their acceptance by industry.
- Providing an analytic basis for the delivery of appropriate levels of power quality and reliability at the various levels of “smart” distribution infrastructure and end-use systems, recognizing the differentiated costs and benefits.
- Conducting consumer studies regarding acceptance of smart grid technologies and applications.
- Examining the business and regulatory policy issues that can help achieve greater consumer participation.

Evaluation & Demonstrations

New technologies and methods are in need of evaluation and demonstrations in terms of performance and conformance with emerging standards & best practices and interoperability requirements. R&D activities will focus on:

- Identifying gaps related to smart grid functionality or gaps in existing technologies and processes that could limit successful, cost-effective roll-out of smart grid systems.
- Developing protocols and methods for testing and evaluating new components and systems.
- Evaluating current industry, laboratory, and government testing capabilities.

FY 2012 Highlights

R&D activities in FY 2012 focused on the following topic areas: Technology Development, Modeling, and Analysis.

The five new projects awarded through the FY 2010 Smart Grid Research, Development, and Demonstration (RD&D) Funding Opportunity Announcement (FOA) to support dynamic optimization of grid operations were evaluated at the DOE Smart Grid Peer Review Meeting on June 7-8, 2012. These projects are in the areas of integrated modeling and analysis tools to automate distribution operations; advanced sensing, monitoring, and control technologies to enhance asset use and grid reliability; and voltage regulation for high penetration of renewable generation. The total public-private investment is $30M+ (DOE share: $19M+). A noted accomplishment was presented by On-Ramp Wireless, whose project demonstrated a wireless communication network solution at two electric utilities (San Diego Gas & Electric [SDG&E] and Southern California Edison) for below-ground distribution automation to improve grid reliability, with a total cost of ownership that is commercially viable for utilities at a large scale.

Eight Renewable and Distributed Systems Integration (RDSI) projects were also presented at the 2012 Peer Review meeting. The primary goals of these projects are to 1) demonstrate at least 15% peak demand reduction on the distribution feeder or substation level through integrating DER and 2) demonstrate microgrids that can operate in both grid parallel and islanded modes. A noted accomplishment was presented by the Fort Collins Zero Energy District (FortZED) project that demonstrated the use of a standardized controls platform to manage diverse DER assets (with a total capacity of over 3.5MW) at 5 partner sites, resulting in reduction of peak load on a single feeder by 20% or more.

Further advances in the GridLAB-D simulation tool by Pacific Northwest National Laboratory were made in FY 2012. These include development and implementation of a dual-objective control framework to manage dual benefit streams from a smart grid technology for building a viable business case. The dual-objective controls developed in GridLAB-D include: managing demand response for the objectives of peak shaving and ramping services; managing energy storage for the objectives of peak shaving and voltage regulation; and managing PEV charging for the objectives of peak shaving and ramping services.

Argonne National Laboratory (ANL) has developed a publicly available tool for analyzing and designing dynamic pricing programs. This Excel-based tool allows utilities to analyze price elasticity of electricity demand from dynamic pricing (time of use [ToU] and/or critical peak pricing [CPP]) pilots, and to project changes in electricity loads as a function of electricity prices and temperatures as specified by utilities. The built-in functions of the tool further allow utilities to use pilot program results to design future dynamic pricing programs to meet utility-defined objectives for peak load reduction and revenue, under a given set of temperatures. This tool is targeted for use by electric utilities and public utility commissioners in designing and evaluating dynamic pricing programs for large-scale implementation beyond the pilot program stage.

Four awards were announced in December 2011 through the FY 2011 FOA on smart grid-capable electric vehicle supply equipment (EVSE) development. The objective of this FOA was to develop and make available to the market in three years smart grid-capable EVSE for AC Level 2 charging at residential and commercial sites for half of the current costs of commercially available EVSE with comparable functionalities. Awardees are: Delta Products Corporation and Siemens Corporate Research for residential EVSE development; and Eaton Corporation and General Electric for commercial EVSE development. The total public-private investment is expected to be $10.8 million, with the DOE share being $6.8 million.

The Program commissioned a FOA in FY 2012 on smart grid data access and announced seven awards in May 2012. The FOA was intended to encourage utilities, local governments, and communities to create programs that empower consumers to better manage their electricity use through improved access to their own electricity consumption data. The seven awardees selected for phase I are: San Diego Gas & Electric; National Information Solutions Cooperative; Pecan Street Inc.; Gulf of Maine Research Institute; City of Dubuque; Balfour Beatty Military Housing Management, LLC; and State of Arizona. For phase II, the Program will select one recipient to apply the tools and software to an entire service territory, region, or community. The total public-private investment for Phase I is expected to be $8.9 million, with the DOE share being $3.2 million.

Complementing the smart grid data access projects are the Apps for Energy prizes awarded to software developers for web and mobile applications that help consumers benefit from the use of their Green Button data. Seven winners were announced in May-June 2012 in three competition categories: best overall app; best student app; and popular choice award. The winners shared a total prize of more than $100,000.

The Program convened a series of regional peer-to-peer workshops to share lessons learned and best practices from smart grid deployments. Each workshop was co-hosted with an American Recovery and Reinvestment Act (ARRA) Smart Grid Investment Grant (SGIG) recipient to provide a forum among stakeholder groups (consumers, utilities, and the various governing bodies) to focus on regional issues. The workshops served to further improve communications with and among stakeholder groups, as well to document institutional factors (markets, regulations, policies) that affect smart grid deployments.

The Program convened two RD&D planning events with key stakeholder groups in FY 2012. One is the Smart Grid R&D Discussion Forum held on June 6 in San Diego, California, immediately before the 2012 Peer Review meeting to seek input from people attending the peer review meeting on three select R&D areas. They are: Modeling & simulation; DR/buildings energy management (BEM) integration; and R&D on PEV and/or photovoltaic (PV) integration with electric distribution grid. Prioritized modeling & simulation capabilities in need of further R&D identified from the Forum are incorporated into section 3.3.5 of this edition of the MYPP. Discussions on the other two areas were more exploratory and concluded with the need to conduct scoping studies before R&D needs can be defined and prioritized.

The 2012 DOE Microgrid Workshop was hosted on July 30-31 in Chicago, Illinois. This workshop was conducted in response to path-forward discussions at the preceding DOE Microgrid Workshop, held in August 2011, which called for sharing lessons learned and best practices for system integration from existing projects in the U.S. (including military microgrids) and internationally. In addition, the purpose of this workshop was to determine system integration gap areas in meeting the DOE program 2020 goals for microgrids and to define specific R&D activities for the needed, but unmet, functional requirements. R&D activities identified from the Workshop are documented in section 3.2.5 herewith, as well as in the Workshop report.[3]

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[3] The 2012 DOE Microgrid Workshop report is available online at http://energy.gov/oe/articles/2012-microgrid-workshop-summary-released.

1. Introduction

1.1. Building a 21^{st} Century Grid: A National Priority

For over a century we've systematically built a complex infrastructure of power plants, regionally connected with high-voltage transmission lines to load centers where lower-voltage distribution lines provide power to homes and businesses. Our nation's power grid ensures our safety and security, and is vital to our continued growth in productivity and prosperity. This national asset, an infrastructure built and maintained on our behalf, is aging, with existing technologies reaching their end of life and others becoming obsolete, overstressed, and unable to meet the demands of high penetration of intermittent renewable energy sources and PEVs. While it has served us remarkably well until now, it is incumbent on us to upgrade it to meet the changing demands and future electric needs of our 21^{st} Century economy and society.

We must build a more efficiently operated grid; one that maintains affordability, reliability, safety, and security for every consumer and meets the needs of a digital and highly interactive economy. Building a smart grid is the first critical step of many for the nation to maintain its technology prowess and prosperity, and brings new tools, techniques, and technologies together in a network of devices aligned and interconnected for superior grid performance. The benefits of a smarter grid are myriad and enduring. At its core is a sophisticated information system that would allow grid operators much greater visibility into the complex inner workings of this large machine to achieve wide-area situational awareness. Greater visibility would enable quick decisions to optimize performance, reduce emissions, and improve reliability. This same information system would provide customers with a window into their own energy use, giving them the tools to make better choices that align with their own values and needs and that achieve greater operational efficiency. Through a new paradigm for involving consumers with interactive loads that respond to the overall needs of the grid, the power providers and the power users work together to create the best possible electric grid at the least cost to the economy and the least impact on the environment.

1.2. Smart Grid Characteristics

The DOE OE defines the smart grid by seven principal characteristics or performance-based functionalities that are needed to meet the demands of the 21st Century. The following characteristics were identified by smart grid stakeholders through regional meetings convened under the Smart Grid Implementation Strategy project of the National Energy Technology Laboratory (NETL),[4] with further refinement through the national Smart Grid Implementation Workshop convened by the OE in June 2008:

- *Enables informed participation by customers*: Consumer choices and increased interaction with the grid bring tangible benefits to both the grid and the environment, while reducing the cost of delivered electricity.

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[4] The Smart Grid Implementation Strategy website is at http://www.netl.doe.gov/smartgrid/.

- *Accommodates all generation and storage options*: Diverse resources with "plug-and-play" connections multiply the options for electrical generation and storage, including new opportunities for more efficient, cleaner power production.
- *Enables new products, services, and markets*: The grid's open-access market reveals waste and inefficiency that need to be removed from the system or corrected while offering new consumer choices such as green power and responsive load products. Reduced transmission congestion leads to more efficient electricity markets.
- *Provides power quality for the range of needs in the 21st century*: Digital-grade power quality avoids productivity losses of downtime, especially in digital device environments.
- *Optimizes assets and operates efficiently*: Desired functionality at minimum cost guides operations and fuller utilization of assets. More targeted and efficient grid maintenance programs result in fewer equipment failures.
- *Addresses disturbances – automated prevention, containment, and restoration*: The smart grid will perform continuous self-assessments to detect, analyze, predict, respond to, and as needed, restore grid components or network sections and/or shift flows/demands with, for example, responsive load and power flow control.
- *Operates resiliently against physical and cyber attacks and natural disasters*: With smarter monitoring/control/analysis systems, the grid deters, copes with, and recovers from security attacks and protects public safety.

An evaluation of today's grid and a future smart grid based on the aforementioned characteristics is shown in Table 1.1.

Table 1.1. Comparison of Today's Grid and the Smart Grid[5]

Characteristic	Today's Grid	Smart Grid
Enables informed and greater participation by customers	More consumers are having access to Green Button data (31 million consumers as of May 2012)	Informed, involved, and active consumers – DR and DER
Accommodates all generation and storage options	Dominated by central generation – many obstacles exist for DER interconnection and operation	Many DER with plug-and-play convenience; distributed generation with local voltage regulation capabilities to support high penetration on distribution systems; responsive load to enhance grid reliability, enabling high penetration of renewables; frequency-controlled loads to provide spinning reserve
Enables new products, services, and markets	Limited wholesale markets, not well integrated – limited opportunities for consumers	Mature, well-integrated wholesale markets; growth of new electricity markets for consumers; interoperability of products
Provides power quality for the range of needs in the 21st century	Focus on outages and primarily manual restoration – slow response to power quality issues, addressed case-by-case	Power quality is a priority with a variety of quality/price options – rapid resolution of issues
Optimizes assets and operates	Limited integration of operational data	Greatly expanded data acquisition of

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[5] Adapted from *The Smart Grid: An Introduction*, available at http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_SG_Book_Single_Pages%281%29.pdf.

Characteristic	Today's Grid	Smart Grid
efficiently	with asset management – business process silos limit sharing	grid parameters – focus on prevention, minimizing impact to consumers
Addresses disturbances – automated prevention, containment, and restoration	Responds to prevent further damage – focus is on protecting assets following a fault	Automatically detects and responds to problems – focus on prevention, minimizing impact to consumers, and automated restoration
Operates resiliently against physical and cyber attacks and natural disasters	Vulnerable to inadvertent mistakes, equipment failures, malicious acts of terror and natural disasters	Resilient to inadvertent and deliberate attacks and natural disasters with rapid coping and restoration capabilities

1.3. Role of DOE Smart Grid Research and Development Program

The OE carries out a variety of research, development, demonstration, analysis, technology transfer, and technical coordination activities related to modernization of the nation's electric T&D system and implementation of smart grid technologies, tools, and techniques. The OE—working with the national laboratories, industry, and academia—has the opportunity to provide new leadership to the power industry and accelerate the adoption of new technologies into the power grid so that the U.S. can become a global leader in providing clean, reliable, and affordable electricity.

The Smart Grid R&D Program within the Research and Development Office of the OE, in accordance with Title XIII of the Energy Independence and Security Act of 2007 (EISA),[6] is tasked with accelerating the deployment and integration of advanced communication, control, and information technologies that are needed to modernize the nation's electric delivery network. The role of the Program is thus to support the OE mission by focusing on modernizing the portion of the electric delivery infrastructure that encompasses all of the subsystems, components, devices, equipment, and systems in electric distribution grid and consumer domains, including their interfaces and integration with transmission and generation systems.

1.4. Role of the MYPP

A smart grid would integrate advanced functions into the nation's electric grid to enhance reliability, efficiency, and security, and would also contribute to the climate change strategic goal of reducing carbon emissions. These advancements will be achieved by modernizing the electric grid with advanced control concepts and information-age technologies, such as microprocessors, communications, and advanced computing, information, and sensor technologies. Achieving enhanced connectivity and interoperability between such technologies will require open system architecture as an integration platform and commonly shared technical standards and protocols for communications and information systems. To realize smart grid capabilities, deployments must integrate a vast number of smart devices and systems (Figure 1.1).

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[6] Available at http://www.ferc.gov/industries/electric/indus-act/smart-grid/eisa.pdf

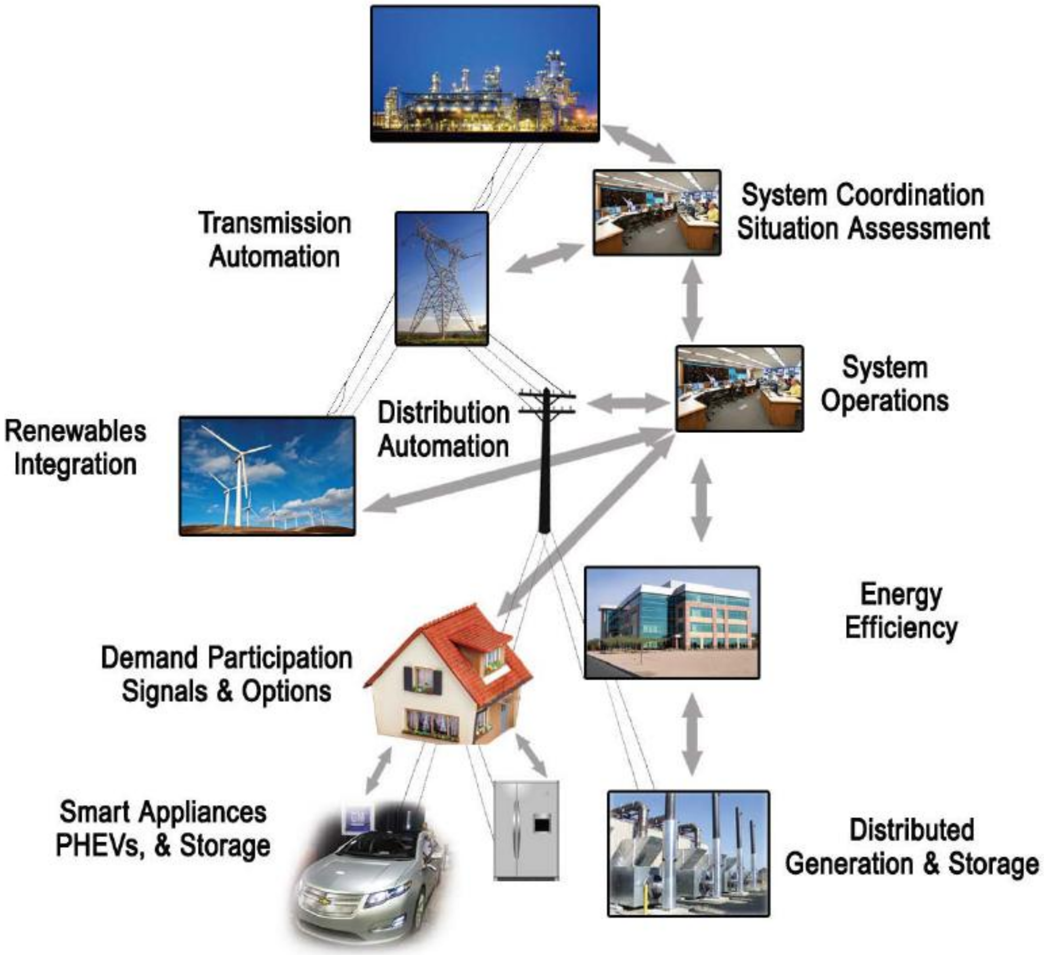

Figure 1.1. Smart Grid Components

Foundational to reaching these capabilities is a comprehensive and rigorous R&D effort that advances both the underlying science and technology required. A proposed R&D plan is discussed in this MYPP, which includes issues such as distributed communications/control, interoperability, and cyber security, as well as the effect of consumer behavior on the operation of the grid; the effect of complex, adaptive, distributed control; and the value of a new generation of simulation tools.

1.5. Vision

The vision of the Smart Grid R&D Program is that:

By 2030, the power grid has evolved into an intelligent energy delivery system that supports plug-and-play integration of dispatchable and intermittent low-carbon energy sources, and provides a platform for consumer engagement in load management, national energy independence, innovation, entrepreneurship, and economic security. This smart grid supports the best and most secure electric services available in the world and connects everyone to abundant, affordable, high quality, environmentally conscious, efficient, and reliable electric power.

This vision is in close alignment with the OE mission – to lead national efforts to modernize the electric grid; enhance the security and reliability of the energy infrastructure; and mitigate the impact of, and facilitate recovery from, disruptions to the energy supply.

Foundational/crosscutting requirements for achieving this vision include:

- High-speed, secure, broadband communications backbone(s) for two-way information flow through smart meters, comparable gateway devices, and electric infrastructure.
- Standards for end-to-end cyber security protection, interoperability, and worker safety, education, and training.

Furthermore, the smart grid infrastructure will include:

- Automated distribution systems and modeling for wide area visibility, outage prevention, and accelerated restoration and optimization.
- Automated customer systems for smart appliances and buildings capable of DR and maintenance for increased efficiency.
- Mechanisms for electricity cost and price transparency at wholesale and retail levels for widespread use of dynamic and appropriate pricing and DR.
- High penetration of distributed and renewable resources, including local voltage regulation and energy storage for addressing intermittent sources.

1.6. Scope of the MYPP

The Smart Grid R&D Program activities will primarily focus on distribution systems and consumer devices, including interfaces and integration with transmission and generation systems. The major R&D topic areas include:

- **Standards & Best Practices** for electrical and communications interconnection, integration, interoperability, conformance test procedures, and operating practices.
- **Technology Development** in advanced sensing and measurement, integrated communications and security, advanced components and subsystems, advanced control methods and system topologies, and decision and operations support.

- **Modeling** accurately the behavior, performance, and cost of distribution-level smart grid assets and their impacts at all levels of grid operations from generation to transmission and distribution.
- **Analysis** of measured data and simulations to better understand the impacts and benefits concerning capacity usage, power quality and reliability, energy efficiency (EE), operational efficiency, and clean technology, as well as economic/business environment and crosscutting goals.
- **Evaluation & Demonstrations** of new technologies and methods in terms of performance and conformance with emerging standards & best practices and interoperability requirements.

1.7. Program Coordination

The Smart Grid R&D Program operates a network of partnerships with other federal offices and agencies, electric utilities and industry, national laboratories, universities, and industry associations. These partnerships include efforts of the federal Smart Grid Task Force that the OE established under the authorization of EISA Title XIII to provide national leadership in coordinating and integrating smart grid activities across federal agencies. Task Force members include representatives from the DOE's OE, Office of Energy Efficiency and Renewable Energy (EERE), and NETL; the Federal Energy Regulatory Commission (FERC); the Department of Commerce's NIST, International Trade Administration, National Telecommunications and Information Administration, and National Oceanic and Atmospheric Administration; the Departments of Agriculture, Defense, and Homeland Security; the Environmental Protection Agency (EPA); the U.S. Trade and Development Agency; the Federal Trade Commission; the Federal Communications Commission (FCC); and the Office of Science and Technology Policy. Other collaborative efforts in support of the EISA Title XIII implementation include support to NIST in coordinating development of a framework for interoperability standards, and production of reports to Congress with input from the Task Force on the status of smart grid implementation across the country and the security implications of smart grid devices and capabilities. Furthermore, the Smart Grid R&D Program coordinates with the FCC on addressing communications technologies for the smart grid. The demand for integrated communication systems and the foreseeable benefits can be accelerated by federal investment in programs that support the understanding and adaptation of such systems by end users.

The Smart Grid R&D Program also aims to coordinate its activities with private companies, utilities, manufacturers, states, cities, and other partners on cost-shared development projects funded under the ARRA of 2009, which includes $3.4 billion in smart grid investment grants for commercial applications and $435 million for smart grid regional demonstrations. Another example is coordination with the U.S. DRIVE (Driving Research and Innovation for Vehicle efficiency and Energy sustainability) on development of smart grid–capable EVSE. The U.S. DRIVE partners include the DOE, automobile industry, electric utility industry, and fuels industry.[7] Furthermore, the Smart Grid R&D Program has been supporting the establishment and maintenance of the Smart Grid Information Clearinghouse to "make data from smart grid demonstration projects and other sources available to the public." Collaboration is also taking place with industry and national laboratories on development of codes and standards, information dissemination activities, and implementing projects. The DOE has also entered into public/private partnerships with leading champions of the smart grid which include the GridWise® Alliance, the Consortium for Electric Reliability Technology Solutions (CERTS), and the Power Systems Engineering Research Center (PSERC). Partnerships with universities, either individually (such as with Virginia Tech on the Smart Grid Information Clearinghouse and with Software Engineering Institute of Carnegie Mellon University on the Smart Grid Maturity Model) or groups of universities (such as those under the CERTS and PSERC), also ensure that the industry and national laboratories will have an educated resource pool to implement the advanced research concepts and to continue advanced smart grid R&D.

The Smart Grid R&D Program also leverages R&D efforts conducted by other programs and agencies in areas that are complementary and necessary for smart grid development. Among these areas are:

- Basic engineering sciences
- Power electronics materials and devices
- Energy storage systems and technologies
- Building technologies
- Microgrids
- T&D efficiency
- Support for the transportation sector

1.8. Program 2020 Goals

The goals of the Smart Grid R&D Program are to develop, by 2020, commercially viable microgrids, a self-healing electric distribution grid, and enabling technologies for high penetration of DER, DR, and PEVs in distribution grid. These goals support the President's initiatives of generating 80% of America's electricity from clean sources by 2035 and putting one million PEVs on the road by 2015. Figure 1.2 depicts the Program R&D topic areas supporting achievement of the Program goals with quantifiable, trendable, and verifiable outcomes.

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[7] Information about the U.S. DRIVE Partnership can be found at http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/usdrive.html.

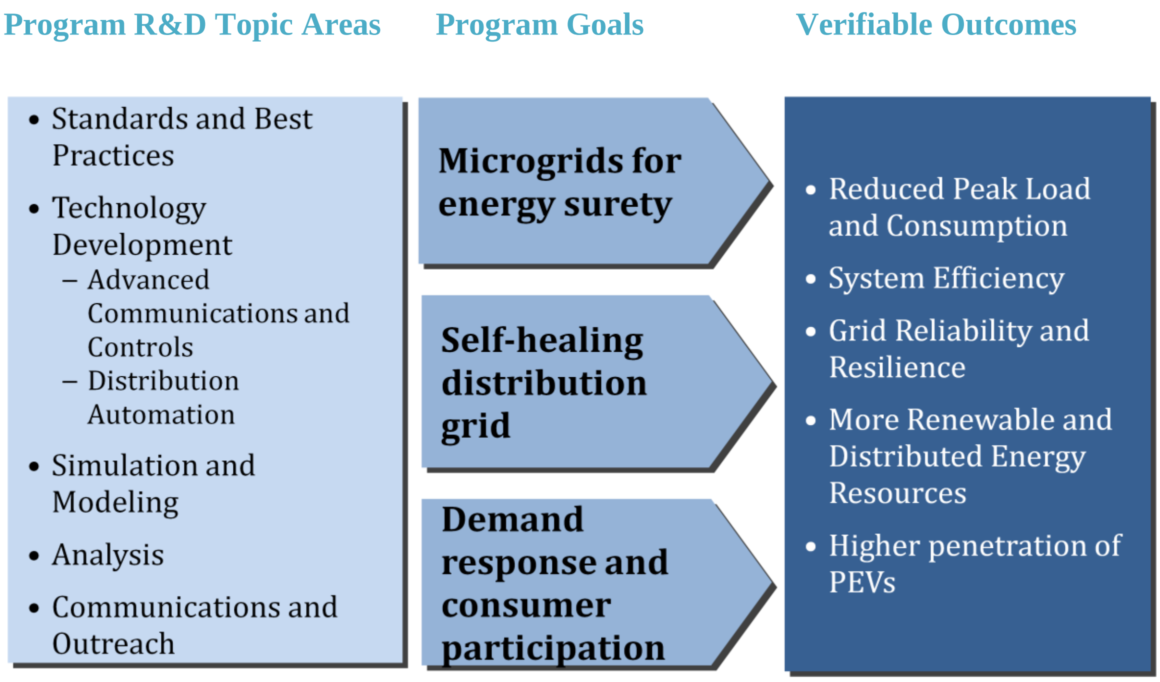

Figure 1.2. Smart Grid R&D Program Topic Areas, Goals, and Outcomes

The Smart Grid R&D Program goals also support the 2010 OE Strategic Goals[8] under the Secretarial Objectives of science, discovery, and innovation; clean secure energy; economic prosperity; and lower greenhouse gas emissions. The sidebar lists two of these Strategic Goals that resonate with MYPP goals.

2010 OE Strategic Plan Guidance:

Goal 1: Develop market-deployable advanced electric transmission and distribution technologies and facilitate expansion of our Nation's electricity infrastructure capacity in order to enhance the adaptability, capacity, reliability, and resiliency of the electric system and promote a low-carbon environment.

Goal 2: Identify, prioritize, coordinate, and improve the protection and restorative capability of national and international critical energy infrastructure assets and key resources—including relevant cyberspace assets—with improved situational awareness, analysis, planning, and preparation; advanced electric transmission and distribution technologies; and expansion of the electricity infrastructure.

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[8] The 2010 OE Strategic Plan is available at http://energy.gov/oe/downloads/office-electricity-delivery-energy-reliability-2010-strategic-plan-web.

2. Program Benefits

A conservative estimate of potential savings resulting from grid modernization is 20% (more than $40 billion/year). According to EPRI, the estimated net investment needed to realize the envisioned power delivery system of the future is between $338 and $476 billion over the next 20 years and the net benefit will be $1,294 to $2,028 billion, leading to a benefit-to-cost ratio range of 2.8 to 6.0.[9] Similar benefits-to-cost results of 5:1 to 6:1 were attained in smart grid studies on the San Diego region[10] and West Virginia.[11] The societal benefits of realizing a smart grid are summarized below, according to the "Understanding the Benefits of the Smart Grid" report[12] by the NETL, and illustrated in Figure 2.1.

- Improved prevention, containment, and restoration of outages. The cost of power interruptions to U.S. electricity consumers is enormous, with a base-case estimate of $79 billion annually and ranging from $22 billion to $135 billion based on particular sensitivity assumptions used in a study by Lawrence Berkeley National Laboratory (LBNL).[13]
- Increased national security through deterrence of organized attacks on the grid.
- Improved tolerance to natural disasters.
- Improved public and worker safety.
- Reduced energy losses and more efficient electrical generation, delivery, and loads.
- Reduced transmission congestion, leading to more efficient electricity markets.
- Improved power quality.
- Reduced environmental impact. The smart grid is capable of providing a significant contribution to the national goals of energy and carbon savings, as documented in two recent reports. One report by EPRI states that the emissions reduction impact of a smart grid is estimated at 60 to 211 million metric tons of CO_2 per year in 2030.[14] A report by Pacific Northwest National Laboratory (PNNL) states that full implementation of smart

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[9] The "Estimating the Costs and Benefits of the Smart Grid" report by EPRI is available at http://my.epri.com/portal/server.pt?Abstract_id=000000000001022519.

[10] The San Diego Smart Grid Study is available at http://www.sandiego.edu/epic/research_reports/documents/061017_SDSmartGridStudyFINAL.pdf.

[11] The West Virginia Smart Grid Implementation Plan is available at http://www.netl.doe.gov/energy-analyses/pubs/WV_SGIP_Final_Report_rev1_complete.pdf.

[12] The "Understanding the Benefits of the Smart Grid" report by the NETL is available at http://www.netl.doe.gov/smartgrid/referenceshelf/whitepapers/06.18.2010_Understanding%20Smart%20Grid%20Benefits.pdf.

[13] The "Cost of Power Interruptions to Electricity Consumers in the United States (U.S.)" report by Lawrence Berkeley National Laboratory, LBNL-58164 (2006), is available at http://www.escholarship.org/uc/item/1d43k4p9.

[14] "The Green Grid: Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid" report by EPRI is available at http://www.smartgridnews.com/artman/uploads/1/SGNR_2009_EPRI_Green_Grid_June_2008.pdf.

grid technologies is expected to achieve a 12% reduction in electricity consumption and CO_2 emissions in 2030.[15]

- Improved U.S. competitiveness, resulting in lower prices for all U.S. products and greater U.S. job creation.
- Optimized use of grid assets.
- More targeted and efficient grid maintenance programs and fewer equipment failures.
- New customer service benefits such as remote connection, more accurate and frequent meter readings, outage detection, and restoration.

3. Research & Development Plan

This section describes five R&D areas pertinent to realizing the Smart Grid R&D Program 2020 goals. Each R&D area description encompasses technical goals and objectives, technical challenges, technical scope, status of current development, technical tasks, milestones, and significant accomplishments according to fiscal year. In deriving technical tasks to be supported by the Smart Grid R&D Program, the following criteria were applied:

- Hindered by lack of standards or in conflict with standards
- Not being addressed by industry or other federal R&D activities
- Longer-term, high-risk developments
- Transformative (e.g., challenge status quo), high payoff
- Feasible given the likely federal R&D budget

The Smart Grid R&D Program's role is thus to fund *long-term, high-risk* R&D in *high-impact* technologies to minimize the risk of adoption by stakeholders that are responsible for the development of the smart grid, namely utilities, equipment manufacturers, and consumers. Such activities should have a high impact, enabling the grid to be transformed in a way that would have been impossible or take much longer without a federally supported research program. Short-term R&D should only be funded to close critical gaps that are not being addressed by industry or other federal entities.

It is important that the Smart Grid R&D Program advances research and development concepts far enough to expand their use into subsystems and applications for the smart grid. These advancements need to reach a level where industry is able to pick them up and put them into practical use. The Smart Grid R&D Program, therefore, needs to be broad, reaching into devices and basic concepts as well as system issues, but also reaching end-use customers such as utilities where appropriate. Partnerships between the national labs, industry (including venture capital-funded startups), and universities will help enable this broad spectrum of activities with limited budgets.

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[15] "The Smart Grid: An Estimate of the Energy and CO_2 Benefits" report by PNNL is available at http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19112.pdf.

3.1. Standards & Best Practices

Standards and best practices support the advancement of smart grid technologies and implementation. Standardized interconnection, integration, and interoperability[16] requirements, conformance test procedures, operating practices, and consumer education facilitate the evolution from our existing legacy electric power system into a smart grid.

Standards and best practices should enhance understanding and defining of smart grid interoperability in the distribution grid with end-use applications and loads. The goal of interoperability is to achieve seamless operation and control for electric generation, delivery, and end-use benefits while permitting two-way power flow with communication and control. For interoperability, both interconnection and intra-facing frameworks and strategies need to be addressed in the standards and best practices. To accomplish these goals, there should be a focus on interoperability promoting better integration of energy, information, and communications technologies.

Areas of interest include standardized interconnection, integration, and interoperability requirements, test procedures, and operating practices related to: equipment and systems (such as DER, PEVs, and energy storage), interconnection equipment, DR, communications and control systems, and electric power protection systems.

Interoperability operational considerations include responsiveness to changing (non-steady) normal and abnormal conditions (e.g., intermittency and robustness), asset utilization, and technical requirements related to business and policy cases. Further interoperability operational considerations include systems and equipment that are interactive (load/energy management, voltage and reactive support, etc.). These considerations should be taken into account for standards and best practices applicable to utility portals in residential, commercial, industrial, and distribution grid facilities (e.g., substations and intelligent grid devices) and user portals (e.g., utility customers, Independent System Operators [ISOs]/Regional Transmission Organizations [RTOs], regulators, third parties).

3.1.1. Technical Goals and Objectives

The technical goals and objectives are to facilitate the evolution from the existing power system into a smart grid by:

- Developing, maintaining, and harmonizing national and international standards on interconnection, interoperability, and cyber security requirements and conformance test procedures for DER.

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[16] Interoperability means the seamless, end-to-end connectivity of hardware and software from the customers' appliances all the way through the T&D system to the power source. Reference: GridWise Architecture Council, "Introduction to Interoperability and Decision Maker's Interoperability Checklist, v1.5," available at http://www.gridwiseac.org/about/publications.aspx.

- Developing and maintaining legacy and advanced distribution system protection, operations, and automation best practices.
- Developing best practices to allow for improved markets by defining reliability and ancillary service requirements and clarifying roles of entities within the smart grid, such as Load Serving Entities (LSE), aggregators, Energy Management Systems (EMS), and ISOs.
- Developing best practices to manage PEV charging and "roaming" from one location to another by leveraging lessons learned from industries such as wireless telecommunications.

3.1.2. Technical Challenges

To accelerate the development and adoption of interoperable smart grid technologies, consensus-based standards need to be developed and tested. Development and harmonization of national and international standards and codes and conformance assessment through certification and laboratory accreditation are necessary to ensure that electric power system reliability, operation, and safety will not be compromised. Implicit in standards development is the need for concurrent validation and testing. This is especially requisite for the advanced hardware and grid operations and communications for the interconnection, interoperability, and control of smart grid equipment, systems, and subsystems.

Many technical characteristics unique to smart grid pose new requirements that must be addressed in standards. Cyber security standards for energy are a relatively new concept compared to regulatory and safety standards that have existed for decades. Historical approaches that can provide valuable lessons learned are lacking. In addition, the smart grid architecture design is technologically diverse, complex, and distributed with numerous accessible components. Standards for other critical infrastructures may be leveraged, but cyber security standards for the smart grid must include guidance for new and emerging technologies, address critical data integrity, and manage the interconnection of dynamic architectures.

Cyber security for energy systems must address both the well-established need for power system reliability and the new area of market confidentiality and consumer privacy. Although utilities have been successfully addressing power system reliability though redundancy, wide area visibility, contingency analysis and other means, and the North American Electric Reliability Corporation (NERC) has developed some security standards for the bulk power system, significant additional work is needed to focus on the remaining areas of the smart grid, such as distribution system reliability and consumer privacy. For instance, it is necessary that cyber security standards address each physical and logical area within the distribution system and its interface to the transmission system and the customer. NIST has identified many of these requirements, but translating the high level NIST requirements into practical standards, policies, and technologies will require significant effort.

While power system reliability and confidentiality are the key security requirements, they rely on data integrity to provide accurate information for operating the smart grid. Layered security measures—including prevention, deferral, detection, coping, recovery, and auditing—provide a minimum level of assurance across a diverse architecture with many technologies. The potentially millions of accessible nodes require significant cyber security considerations, and the role of standards can assist in meeting this requirement. These security standards should address technology, people, and processes (i.e., hardware, software, protocols, data warehousing and management, human interaction, and coordination with physical security).

In addition to cyber security, the protection, operation, and automation of the grid will need to evolve to accommodate new technology as smart grid components are deployed. Currently, electric power system (EPS) operators have maintained distribution system protection, operation, and automation in order to keep reliability of the grid intact without fully addressing cyber security. Challenges and opportunities will exist with the integration of new protective devices, and best practices for operations will need to be developed. There are many ways to operate the EPS, and best practices vary greatly from region to region, utility to utility, and across diverse markets. Examples include the implementation of conservation voltage reduction (CVR), reactive support from the distribution to transmission system, payment methods for reliability services, and reliability services from responsive load.

There is also a need to improve the reliability and ancillary service definitions that have been used in the legacy power system. Ancillary service definitions and requirements have been based, in large part, on guidelines that have been "handed down" over decades of power system operation. For example, the amount of spinning reserve the operator carries for reliable system operation, or the duration required for the spinning reserve when deployed, is determined, in some control areas, by historical guidelines and not by rigorous system modeling and analysis to determine the actual required parameters. A determination of the actual required ancillary service parameters may result in a reduction in emissions and improvement in efficiency. Also, it is likely that reliability services supplied by responsive load may actually provide a greater impact, per MW, than the same service from generation because load response is faster and more accurate, and dropping the load also reduces the T&D flows and related losses.

Presently, major differences exist among ISOs/RTOs, control areas, and vertically structured utilities regarding the market methods used to provide reliability services for the bulk power system. These differences are not only due to the fact that some areas of the country have restructured markets while others have not, but are also due to differences in philosophy, with some utilities planning to derive a complete range of reliability services from distribution, including spinning reserve, regulation, local voltage regulation, and voltage support up to the transmission grid. Other areas are planning to use the market only for peak shaving. There is a need to conduct research and demonstrations to show the significant emissions reductions and reliability and efficiency improvements from markets for load- and distribution-based services.

There is presently a misunderstanding as to the exact roles in the smart grid of the LSE, customer, aggregator, EMS, smart appliance, etc. Surveys and studies are necessary to define the exact services each role can provide in the smart grid and to determine the qualifications needed to perform each service reliably and efficiently.

3.1.3. Technical Scope

The scope of this research plan covers standards and best practices for the electric power distribution system and its interface requirements with the transmission system, system markets, EPS operators, and local customers and appliances. The distribution systems in the U.S. include both radial distribution circuits and secondary distribution network circuits. There is a predominance of multi-grounded, mixed-phase distribution circuit systems. Especially at the lower voltage levels, these circuits can be one-, two-, or three-phase distribution to consumers. This section covers standards and best practices relating to smart grid implementation, including:

- Interoperability standards for smart grid components and the overall system
- Interconnection standards for DER, including generation and storage
- Cyber security requirements for smart grids
- Exploratory and conformance test procedures related to cyber security standards and interconnection and interoperability
- Interfaces with the transmission system and local loads, including demand response
- Improved reliability and ancillary service definitions based on system analysis
- Market systems clarification and discussion among regions and states
- Improved understanding and definition of roles of entities within the smart grid (LSE, aggregators, EMS, ISOs/RTOs, etc.)
- Identification of gaps/conflicts in existing standards, including but not limited to NERC, FERC, regional, and IEEE standards
- Distribution system protection, operations, and automation practices

3.1.4. Status of Current Development

Under the EISA of 2007, NIST was assigned "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…"[17] As part of the *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0,*[18] NIST has added 22 standards, specifications, and guidelines to the 75 standards NIST recommended in the 1.0 version of January 2010 as being applicable to the Smart Grid. There is a need to evaluate these identified standards and their relevance to the distribution aspect of smart grids.

In the areas of interconnection and interoperability, NIST identified the following standards gaps, issues, and extensions specific to topics covered by the IEEE 1547 interconnection standards and the IEEE 2030 standard development:

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[17] EISA Title XIII, Section 1305.

[18] NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0, NIST Special Publication 1108R2, February 2012 (available at http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf).

- Energy Storage Systems, e.g., IEEE 1547 extensions for storage system specific requirements (P1547.8) and IEC 61850 modeling extensions
- Distribution Grid Management Initiatives, e.g., Common Information Model (CIM) and IEC 61850 extensions
- Voltage Regulation, Grid Support, etc., e.g., develop specifications in P1547 and/or P2030 series
- Management of DER, e.g., planned island systems
- Static and Mobile Electric Storage, including both small and large electric storage facilities
- Electric Transportation and Electric Vehicles

In 2009, IEEE initiated the development of P2030: "Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS) and End-Use Applications and Loads." This standard, published in September 2011 as IEEE Std 2030,[19] provides a knowledge base addressing terminology, characteristics, functional performance and evaluation criteria, and the application of engineering principles for smart grid interoperability of the EPS with end-use applications and loads.

In the area of cyber security, NIST published the *Guidelines for Smart Grid Cyber Security* (NISTIR 7628),[20] which presents an analytical framework that organizations can use to develop effective cyber security strategies tailored to their particular combinations of Smart Grid-related characteristics, risks, and vulnerabilities. The *Guidelines* report recognizes cyber security as a critical, cross-cutting issue that must be addressed in all standards developed for Smart Grid applications.

In the area of DR, Open Automated Demand Response Communications Specification, also known as OpenADR, has been developed as a communications data model designed to facilitate sending and receiving DR signals from a utility or independent system operator to electric customers. The intention of the data model is to interact with building and industrial control systems that are pre-programmed to take action based on a DR signal, enabling a DR event to be fully automated, with no manual intervention. OpenADR is one element of the smart grid information and communications technologies that are being developed to improve matching between electric supply and demand.

In the markets and reliability areas, huge differences in operational methods exist between regions, but there are still commonalities that can be addressed. The interfaces to use load as a resource are well developed and in routine use in some areas of the country, but still undeveloped in others. Some areas have plans for an intermediary agent such as an aggregator

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[19] Available at http://grouper.ieee.org/groups/scc21/2030/2030_index.html.

[20] Available at http://www.nist.gov/smartgrid/upload/nistir-7628_total.pdf.

or EMS; in other areas, there is direct dispatch to the individual load by the system operator. These responsive load practices need to be further described, with requirements specified.

Currently there is a need not only to assess existing standards and practices, but also to investigate new methods that could significantly increase efficiency and reduce emissions while maintaining reliability. As a result, new standards for residential and non-residential buildings and the interconnections and interoperability with a smart grid may emerge that should be considered for adoption nationally.

3.1.5. Technical Task Descriptions

The proposed technical tasks are organized into the following priority areas:

Interoperability and Interconnection

- Develop use cases to identify the requirements for interoperability and interconnection of smart grid components and systems.
- Develop exploratory and conformance test procedures related to interconnection and interoperability.
- Support accelerated development of priority smart grid interoperability standards.
- Continue to maintain and update interconnection standards.
- Develop distribution system protection, operations, and automation schemes for the smart grid.
- Provide coordinated technical support to authorities having jurisdiction for adopting and referencing smart grid interconnection and interoperability standards and best practices, e.g., states, regional, and federal entities such as NERC and ISOs/RTOs.

Cyber Security

- Identify security requirements for all “assets” of the smart grid, including equipment, applications, databases, communications, and information flows; develop a security architecture for the smart grid; and identify the set of required standards as a target for gap analysis.
- Identify architectural, functional, and operational areas not addressed in existing standards.
- Identify technologies at the component level that require standards or guidance for security.
- Develop guidance that expands upon the human interaction, life cycle maintenance, and operational controls.
- Develop and validate methods providing cyber secure operation, along with isolation and recovery of systems, to provide a foundation for grid support and allow data exchange among different information system domains and technologies.

Market and Reliability

- Describe system operation models to enhance understanding of power system and market basics.
- Develop clearly defined functional roles for entities in these models.
- Develop clearly defined specifications for reliability services based on system analysis.
- Develop the communication and ratings/specification framework for these functional roles.
- Develop clearly defined specifications for residential and nonresidential buildings and their interconnection and interoperability with the smart grid.

3.1.6. Milestones

Milestones are listed in terms of near-, mid-, and long-term objectives:

Near Term (1-2 years)

- List weaknesses and opportunities in existing standards and practices.
- Initiate priority smart grid interconnection and interoperability standards development (e.g., P1547.8, Recommended practice for establishing methods and procedures that provide supplemental support for implementation strategies for expanded use of IEEE Standard 1547).
- Establish publishable case studies and best practices for the smart grid industry covering interoperability standards, conformance, and certification to support both large and small businesses.

Mid Term (3-4 years)

- Update standards to address smart grid functionality.
- Complete IEEE P1547.8.
- Develop new standards and best practices to address smart grid gaps.

Long Term (5+ years)

- Complete IEEE P2030 Series of Standards.
- Complete conformance test procedures and certification program for smart grid interoperability.

3.1.7. FY 2012 Accomplishments

National Renewable Energy Laboratory (NREL), under the Smart Grid R&D Program funding, has been providing leadership, facilitation, and coordination roles in support of the IEEE in industry-driven, consensus development of interconnection and interoperability series of standards. In FY 2012, the NREL project held the IEEE 1547 Workshop for technical changes discussion and rationale for revision to IEEE Std 1547, and led or represented various sessions for 1547 stakeholder feedback; represented the U.S. on IEC/TC8 Smart Grid Interface/Interconnection standard development led by China; led development of the IEEE P1547.8 (extended use of IEEE Std 1547 that includes voltage regulation; voltage and frequency ride-through, DR penetration limits and effects; grid ancillary services/support/reactive power control; enhanced DR communications; etc.); and facilitated development of the IEEE P2030.2 – Draft Guide for Energy Storage Systems Interoperability with Electric Power Infrastructure.

The GridWise Architecture Council (GWAC) project is led by PNNL to help industry understand how to address and achieve interoperability in smart grid efforts. One key activity of the GWAC is its annual interoperability meeting, the Grid-Interop Forum, which in recent years has drawn as many as 500 participants. The fifth annual GWAC sponsored Grid-Interop 2011 was held in Phoenix, Arizona, from December 5-9, 2011, with the theme of "Implementing Interoperability."

3.2. Technology Development

3.2.1. Technical Goals and Objectives

The objective of the Technology Development topic area is to pursue critical technological advancement in components, integrated systems, and applications that are required to achieve the full potential of the smart grid and transition from the existing EPS. The R&D activities focus on technologies deployed in the distribution system; however, the benefits extend to the entire grid. The goal is to foster the development of smart grid technologies that support high penetration of renewable generation and other DER; diversified service reliability; integration of the electric transportation sector; reduction of system losses; improved security and resiliency to failure and attack; provision of ancillary services by DER; greater customer participation and choice; reduction in operation, maintenance, and integration cost; and increase in overall system efficiency. Technologies should seek to incorporate increasing automation, in alignment with the overarching vision for the smart grid, as automation is the key to efficiently delivering many of these benefits. In addition to increasing functionality and performance, the R&D activities support improvements in safety, reliability, interoperability, and security.

3.2.2. Technical Challenges

Technical challenges that relate to Technology Development include the following:

- **Unclear definition of smart grid architecture and business models**. Grid system architecture can be defined by the topology of the power and communications network and the control algorithms and strategies used. Definitions or visions of smart grid architectures and functionality are still evolving. Therefore, technology requirements to support that architecture are not fully defined, particularly in the case of long-term needs. It is premature to define the smart grid architecture too rigidly, such as using distributed versus centralized controls. To do so would suppress important research concepts and discourage potentially significant breakthroughs. While it is possible to identify the key functionality, several technology solutions may be possible, depending on the ownership, scale, and business models that are envisioned.

- **Integration with legacy systems.** The North American power grid is a large interconnected system that involves thousands of service providers and system operators, tens of thousands of electric generators, hundreds of thousands of miles of lines and interconnections, and hundreds of millions of customers. It is reliable and provides electricity at low cost. While it is clear that smart grid concepts enable an evolution to a more sustainable power grid in the long run, emerging smart grid technologies must be deployed incrementally in the context of a very large, capital-intensive, and complex legacy infrastructure. Addressing intergenerational interoperability is critical to allow the evolution to continue. In this environment, achieving large-scale deployment and adoption of fundamentally new technologies, with potentially new distribution systems topologies and operations practices, is a significant challenge.
- **Wide scope of technologies and domains.** The range of smart grid technologies is quite broad, including: fast and secure communications, better system awareness, more sophisticated protection and control approaches, electric power storage, and systems to aggregate, manage, and control distributed resources (including customer generation and loads). New materials, devices, subsystems, systems, algorithms, and topologies will be needed to realize the smart grid vision. This intelligent grid will rely on ubiquitous sensing, measurement, and communication of that information to the appropriate control locations. It will require new power electronics control of electric power flow within the network and inside the home and enterprise, as the smart grid extends beyond the boundary of the meter. Additionally, this will require new power electronic control in support of the transportation sector. New algorithms and levels of automation are required to realize control of the grid in this information-rich environment. Smart grid technologies are expected to perform varied functions depending on the domain (home, building, microgrid, utility, market); yet, they are expected to interoperate as an integrated system.
- **Evolving nature of standards.** A key challenge is that development and deployment of smart grid components, subsystems, and applications are occurring before performance, interoperability, and cyber security standards are finalized. Insertion of smart grid technology in the absence of clear standards represents added risk.
- **Expected service longevity.** Power system assets are expected to have a long service life, often decades. This translates into a significant challenge from the technology development perspective. Smart grid technologies need to have a high level of reliability while operating in a physical environment that is often harsh. In addition, hardware and firmware platforms need to have the capability and flexibility to adapt to future needs. It is difficult to meet these needs at a reasonable cost to consumers.

3.2.3. Technical Scope

The Technology Development topic area focuses on components, integrated systems, and applications deployed in the distribution system under utility, customer, and third-party ownership or control. R&D activities cover technologies within the following areas:

- *Advanced Sensing and Measurement* to support faster and more accurate response such as remote monitoring and demand-side management.
- *Microgrids* to provide energy surety to critical loads[21] and to control power quality and reliability at the local level.
- *Distribution automation* to reduce system outage duration and frequency.

3.2.4. Status of Current Development

A survey of the status of current development in each of the technology areas is provided below.

3.2.4.1. Advanced Sensing and Measurement

Sensing and measurement can be considered the eyes and ears of the smart grid. Without them, the utility operator, customer, and automated control systems are blind and cannot operate effectively and efficiently. Several key technologies are under development in this area, notably smart meters, cost-effective sensing and energy measurement for home automation and smart appliances, and distribution network sensing. Information aggregation, processing, and visualization are needed to process larger volumes of data (such as from smart meters, prognostic health management (PHM) systems, distribution sensing forecasting subsystems, real-time markets, and distribution phasor monitor units) for integration into the distribution level management systems. Technology advances in software and hardware data aggregation and data-set reduction techniques can reduce the information to a meaningful set that the operator can use. Display visualization is another form of data aggregation and reduction, displaying only the critical information based on measurements.

3.2.4.2. Microgrids

Most grid controls today are centralized. As the smart grid evolves to one with a plethora of distributed renewable generation, storage, and load management, the control schemes will be strongly influenced by the smart grid topology (centralized vs. distributed control). An example of new topology is a microgrid: a small section of the grid that can operate disconnected from (islanded mode) or connected to the rest of the grid. The ability to island from the grid presents challenges in control, safety, security, reliability, and stability in the face of a large percentage of renewable resources that require distributed and potentially complex controls. However, the benefit is that an islandable microgrid can operate for an extended period of time in the face of transmission line or large generation plant outages. The perfect power requirement for critical loads could only be met through advanced distribution operational concepts such as microgrids, where smart grid architectures—embodying an integrated power/communication network and advanced control algorithms and strategies—are needed to achieve not only high system reliability but also cost-effectiveness over redundant backup systems used today. Technology

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[21] Critical loads include hospitals, police and fire stations, data centers, telecom switch centers, semiconductor fabs and foundries, mission-impacting defense and security applications, etc.

development is needed to implement robust, microgrid-friendly features—such as adaptive, distributed, agent-based controls—into active sources, energy management systems, energy storage, and network components to support microgrid operation.

At present, the application of microgrids is limited to military bases, islands, universities, and large industrial complexes given existing business structures and policies. Refer to section 3.2.7.2 for a discussion on microgrid projects under the RDSI program. There is also a significant effort by national laboratories to demonstrate microgrids at test beds and military bases. LBNL is teaming with American Electric Power (AEP) and the University of Wisconsin to apply CERTS microgrid concepts in AEP's Walnut Test Facility in Groveport, Ohio. The CERTS Microgrid Test Bed is being expanded through the addition of new hardware elements: a CERTS compatible conventional synchronous generator; a more flexible energy management system for dispatch; intelligent load shedding; a commercially available, stand-alone electricity storage device with CERTS controls; and a PV emulator and inverter with CERTS controls. CERTS microgrid concepts are also being applied in field demonstrations by the Sacramento Municipal Utility District, Chevron Energy Solutions (RDSI project), and the Department of Defense at Fort Sill and Fort Maxwell. Sandia National Laboratories (SNL) is working on the Energy Surety Microgrid^{TM} methodology, which uses cost/performance data and lessons learned from military bases to develop approaches for implementing high reliability microgrids. So far, 14 military bases have received assessments and/or conceptual designs using the Sandia Energy Surety Microgrid methodology. Furthermore, the DOE is supporting SNL, Oak Ridge National Laboratory (ORNL), Idaho National Laboratory, NREL, and PNNL to work with the Department of Defense (DoD) to conduct the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) at Pearl Harbor-Hickam Air Force Base, Hawaii; Fort Carson, Colorado; and Camp Smith, Hawaii. A key part of SPIDERS is standardization of the design approach, contracting, installation, security, and operation of these microgrids to support future applications. At ORNL, the Distributed Energy Communications & Controls Laboratory is developing controls for inverter-based DER to provide local voltage, power, and power quality support for the campus distribution system. On the simulation side, PNNL has been developing GridLAB-D as a distribution system simulation tool that integrates grid operations at several levels, including microgrids (refer to *Modeling* section for more information).

Under the ARRA, the Smart Grid Demonstration Program (SGDP) has awarded several projects involving combinations of integrating uses of renewable energy resources, distributed generation, energy storage, demand-side management, and charging schemes for PEVs. These projects include: Energy Internet Demonstration by Pecan Street Project Inc. in Texas; Pacific Northwest Smart Grid Demonstration by Battelle Memorial Institute including Portland General Electric's High Reliability Zone (microgrid); Green Impact Zone SmartGrid Demonstration by Kansas City Power and Light in Missouri; and Smart Grid Regional Demonstration by Los Angeles Department of Water and Power in California.[22]

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[22] Information on the SGDP projects is available at http://www.smartgrid.gov/recovery_act/project_information?keys=&project%5B%5D=2.

3.2.4.3. Distribution Automation

One of the overall goals of the smart grid will be the development of a more automated and flexible distribution system, capable of anticipating and responding to disturbances or malicious attacks while continually optimizing its own performance. Self-healing features such as the ability to dispatch DER and reconfigure power flow to isolate faulted or damaged equipment could be implemented to increase grid security in response to malicious attack. The overall benefits from cost-effective distribution grid automation will include not only enhanced reliability, but also innovative customer services, reduced operations and maintenance (O&M) costs, and increased throughput on existing lines via more effective power flow control. Distribution automation is already in early deployment; however, the evolution of the distribution grid from one with radial power flow and little automation to a more flexible, automated, and self-healing grid with many distributed resources will have to address new challenges, including control complexity and protection.

3.2.5. Technical Task Descriptions

The proposed technical tasks are organized by each of the three technical areas described above:

Advanced Sensing and Measurement:

- Develop distribution system sensing (including advanced fault detection, isolation, and restoration [FDIR] technology) and customer-side sensing for enhanced awareness of distribution system conditions.
- Develop information aggregation, processing, and visualization techniques to effectively process large volumes of data for integration with distribution energy management systems.
- Develop diagnostic, service, and maintenance tools.

Microgrids: The activities described below were defined at the 2012 DOE Microgrid Workshop.

- System Architecture Development:
    - Definition of microgrid applications, interfaces, and services. Define the following: an ideal microgrid architecture, use cases, and interfaces to reference existing standards (interconnection versus communication versus information.
    - Open architectures that promote flexibility, scalability, and security. Develop interoperable distributed controls and flexible architecture to facilitate different applications.

- Modeling and Analysis:
    - Performance optimization methods and uncertainty in the modeling and design process. Develop a standard set of collaborative tools that addresses uncertainty, has a more holistic approach (to integrated energy systems, communications, vehicles, combined heat and power systems, etc.), and broadly assesses value streams; validate the tools on both domestic and international systems.

- Power System Design:
    - DC power distribution systems. Establish codes and standards for DC applications in residential, commercial, and industrial settings; develop standard design methodologies and software tools; develop DC system control algorithms; implement a push-and-pull strategy for DC microgrids, and develop advanced power electronics (lower cost, higher function and reliability).
    - Microgrid integration. Develop the following: a resource guide (handbook) of available products, costs, installation methods, valuation methods, etc.; standard and observable models to be used in modeling and analysis; standard analysis methods and software models; surety design methods and metrics for reliability and security; and advanced power electronics and advanced controls.

- Steady State Control and Coordination:
    - Internal services within a microgrid. Develop a standard set of hardware and software that supports the communication protocols and cyber security standards already developed to allow DER to plug and play; develop three-phase estimators based on phasor measurement units (PMUs) and compatible instrumentation for run time control; develop a better understanding of methods of decoupling frequency and voltage; and demonstrate a system that can synchronize and reconnect a microgrid under all edge conditions (high PV penetration) for all classes of microgrids.
    - Interaction of microgrid with utility or other microgrids. Evaluate microgrids against other existing utility mitigation tools and schemes; evaluate potential effects of multiple microgrids on the stability of the grid and potential regulatory policies, economic incentives, and control schemes that could be used to mitigate the negative effects; develop tools for distribution to manage microgrids and their resources in cooperation with other distribution resources (assets) in "RDO" (regional distribution operator); and develop a technical, operational, and economic model to demonstrate the value of microgrids to utilities through simulation and case studies.

- Transient State Control and Protection:
    - Transient state control and protection. Define impact of types of communication and identify requirements; develop 3-phase unbalanced dynamic stability analysis models and a Reference Study for transient stability analysis of microgrids; develop technically mature, commercially available autonomous transition control and protection concept and products meeting the defined capabilities; and validate standard microgrid component models for protection and transient studies.

- Operational Optimization:
    - Operational optimization of a single microgrid. Develop real-time (RT) and near-RT controls that incorporate optimization; evaluate various optimization techniques as applied to microgrid operations; and develop methodology for comparing microgrid baseline to optimized microgrid operations for potential input into business case analysis.

  - Operational optimization of multiple microgrids. Develop RT and near-RT controls that incorporate optimization between multiple microgrids; develop methods to negotiate objectives and optimizations between multiple microgrids (between different microgrid integrators); evaluate various optimization techniques as applied to multiple microgrid operations; and develop methodology for comparing multiple microgrid baseline to optimized microgrid operations for potential input into business case analysis.

Distribution Automation:

- Develop integrated distribution management systems that integrate disparate distribution operational systems with advanced smart grid applications into one platform.
- Develop distribution grid automation technologies.
- Develop automated protection and control technologies.

3.2.6. Milestones

The milestones for the prioritized technical tasks are listed as near-, mid-, and long-term projects:

Near Term (1-2 years)

- Novel additions and improvements to the advanced metering infrastructure (AMI).
- Concepts in home-area and distribution-level, low-power, secure communications.
- Intelligent control of PEV charging.
- Data reduction and visualization for utility operator assimilation.

Mid Term (3-4 years)

- Advanced ubiquitous voltage, current, and phasor measurements in distribution.
- Demonstration of attack resilience and rapid restoration.
- Novel tools for line personnel for operations and installation in the smart grid.

Long Term (5+ years)

- Commercial microgrids achieving cost parity with the non-integrated baseline solutions.
- Sensors and sensor networks for renewable resource prediction.
- A self-healing smart grid.
- PHM in the smart grid.
- Distributed controls of loads, storage, and generation.
- Technology for advanced market concepts.

3.2.7. FY 2012 Accomplishments

3.2.7.1. Advanced Sensing and Measurement

Five new projects were awarded in November 2010 through the FY 2010 Smart Grid RD&D FOA to support dynamic optimization of grid operations. These projects are in the areas of integrated modeling and analysis tools to automate distribution (see section 3.2.7.3 for the two awards in this area); advanced sensing, monitoring, and control technologies to enhance asset use and grid reliability; and voltage regulation for high penetration of renewable generation. The total public-private investment is $30M+ (DOE share: $19M+).

Two awards were made under the topic area of advanced sensing, monitoring, and control technologies. For the first award, the project by On-Ramp Wireless, Inc., teaming with Schweitzer Engineering Labs is to develop and demonstrate a centrally managed, wide-area wireless distribution grid monitoring system (including fault circuit indicators and transformer monitoring) capable of monitoring underground and other hard-to-reach distribution circuits to improve performance metrics (i.e., SAIFI, CAIDI, SAIDI), support dynamic load management and predictive maintenance, and enable future remote monitoring applications. This wireless network monitoring system was demonstrated in the territories of Southern California Edison and SDG&E for below ground distribution automation, at a total cost of ownership that is commercially viable for utilities to deploy at large scale.

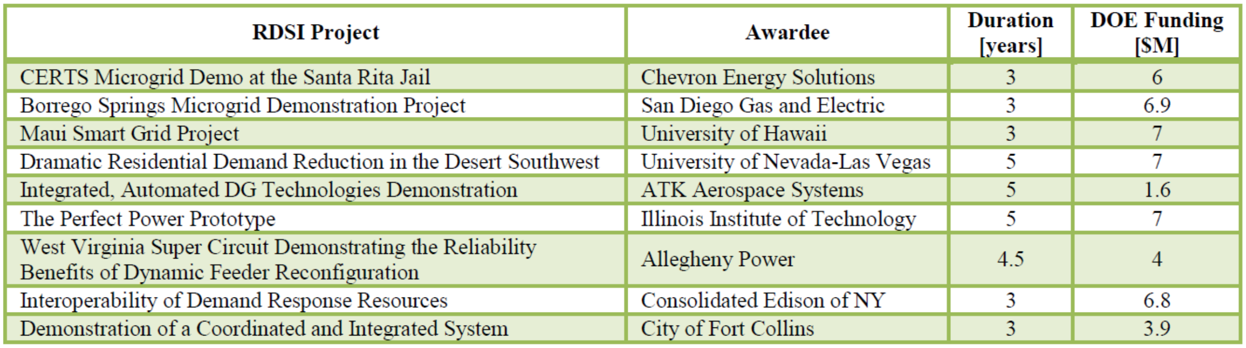
For the second award, the project by ABB Inc. and its partners is to develop and demonstrate a real-time distribution feeder performance monitoring, advisory control, and health management system. This system will use digital data from distributed sensors and substation Intelligent Electronic Devices to continuously monitor performance of distribution feeders and provide timely decision support information to operators in (near) real-time. The goals include reducing the frequency and duration of unplanned outages and mitigating anticipated or confirmed feeder anomalies, asset failures, and power quality issues. Data from Xcel Energy’s distribution feeders will be used for testing and developing applications for eventual field deployment.

One award was made under the topic area of voltage regulation and overvoltage protection for high penetration of renewable generation. Varentec and its partners are applying an advanced circuit topology to deliver fast response voltage regulation and dynamic reactive power compensation. Their technology can connect directly to medium-voltage distribution lines (e.g., 4,160 V to 13,800 V) without requiring a 60-Hz transformer, operate at higher efficiencies than existing systems, and integrate battery energy storage while maintaining low losses and a fast response time. This advancement in power electronics lays the groundwork for a wide range of next-generation products that do not require heavy, large conventional transformers that consume energy even when dormant and incur additional 2-3% losses each way in bi-directional operation.

3.2.7.2. Microgrids

Nine RDSI projects were continuing in FY 2012, aiming to 1) demonstrate at least 15% peak demand reduction on the distribution feeder or substation level through integrating DER and 2) demonstrate microgrids that can operate in both grid parallel and islanded modes. The application of technologies in an integrated fashion has the potential to allow more power to be delivered through existing infrastructure, thereby deferring transmission and distribution investment, and to increase the reliability of the grid by adding elements that make it more stable and reconfigurable. Other potential benefits include addressing vulnerabilities in critical infrastructure, managing peak loads, lowering emissions, using fuel resources more efficiently, and helping customers manage energy costs. The total value of the RDSI program will exceed $100M, with approximately $55M from the DOE over five years and the rest through participant cost share. The RDSI projects are listed in the table below, and eight of the nine projects presented their progress at the Smart Grid Peer Review meeting.[23]

LIST OF RDSI PROJECTS AND THEIR DURATION AND FUNDING AMOUNTS



RDSI Project	Awardee	Duration [years]	DOE Funding [$M]
CERTS Microgrid Demo at the Santa Rita Jail	Chevron Energy Solutions	3	6
Borrego Springs Microgrid Demonstration Project	San Diego Gas and Electric	3	6.9
Maui Smart Grid Project	University of Hawaii	3	7
Dramatic Residential Demand Reduction in the Desert Southwest	University of Nevada-Las Vegas	5	7
Integrated, Automated DG Technologies Demonstration	ATK Aerospace Systems	5	1.6
The Perfect Power Prototype	Illinois Institute of Technology	5	7
West Virginia Super Circuit Demonstrating the Reliability Benefits of Dynamic Feeder Reconfiguration	Allegheny Power	4.5	4
Interoperability of Demand Response Resources	Consolidated Edison of NY	3	6.8
Demonstration of a Coordinated and Integrated System	City of Fort Collins	3	3.9

One of the nine projects, the Demonstration of a Coordinated and Integrated System project by the City of Fort Collins, Colorado, was completed in FY 2012. The project demonstrated the use of a standardized controls platform to manage diverse DER assets (a total capacity of over 3.5MW) at 5 partner sites, resulting in reduction of peak load on a single feeder by 20% or more. The controls platform incorporates a developed peak load management algorithm to manage assets to achieve specific project objectives within predefined constraints, while allowing local controls by site partners via their existing building automation systems or SCADA. The other eight RDSI projects are progressing according to their project plans.

In response to path-forward discussions at the August 2011 DOE Microgrid Workshop, the Program held the 2012 Microgrid Workshop on July 30-31 at the Illinois Institute of Technology (IIT) facilities in Chicago, Illinois, to share lessons learned and best practices for system integration from existing projects in the U.S. (including military microgrids) and internationally. In addition, the purpose of this workshop was to determine system integration gap areas in meeting the DOE program 2020 targets for microgrids and to define specific R&D activities for the needed, but unmet, functional requirements. The DOE program targets, affirmed at the

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[23] Project presentation files from the Smart Grid Peer Review in San Diego, CA, on June 7-8, 2012, are available at http://events.energetics.com/SmartGridPeerReview2012/agenda.html.

August 2011 workshop and documented in the workshop report, are to develop commercial scale microgrid systems (capacity <10 MW) capable of reducing outage time of required loads by >98% at a cost comparable to non-integrated baseline solutions (uninterrupted power supply plus diesel genset), while reducing emissions by >20% and improving system energy efficiencies by >20%, by 2020. The workshop had a total of 100 registrants, representing vendors, utilities, national laboratories, universities, research institutes, and end users. Among them, 13 representatives from eight foreign countries (Belgium, Canada, Germany, Greece, Japan, South Korea, Romania, and the UK) participated in the workshop. Two breakout groups focused on planning and design (system architecture development, modeling and analysis, and power system design) and operations and control (steady state control and coordination, transient state control and protection, and operational optimization). Specific R&D activities identified at the workshop are listed in section 3.2.5 and are being used by the Program to guide ongoing R&D by national labs and to further refine R&D requirements for the FOA planned for FY 2014.

3.2.7.3. Distribution Automation

The FY 2010 Smart Grid FOA awarded two projects on modeling under the distribution automation topic area. One award is to Alstom, which involves integration of disparate distribution operational systems (Distribution SCADA, switching operations, outage management, etc.) into one platform, as well as integration of advanced applications such as DER modeling, load forecasting, DER scheduling, AMI, demand response, and advanced and adaptive protection. In addition, the integrated platform will facilitate timely data/information exchanges with offline simulation and modeling tools for decision support functions under "what-if" scenarios. The integrated system will support distribution automation, thus improving SAIDI performance. The table below shows tracking targets for Alstom's integrated platform.

Year	2011	2012	2013	2014	2020
Performance Targets					
Efficiency (%) National	94	94.15	94.30	94.45	97
Load Factor (%) Duke Energy	65	66.3	67.6	68.9	78 (↑20%)
SAIDI (min) Duke's McAlpine Substation	144	141.12	138.24	135.36 (↓6%)	118.08 (↓20%)
Outage Reduction for Critical Loads (%) Duke's McAlpine Substation	98.6	98.62	98.65	98.68	>98 98.85

The second award is to the Boeing Company, which will demonstrate the secure interoperability capabilities of the Boeing Distribution Management System with legacy and new services for a smart, highly-automated, and self-healing distribution management system (DMS). The automated DMS will enable the seamless integration of customer-owned DER without compromising the reliability of power from the utility's legacy distribution system. This system will enable conversion of microgrids into reliable energy, capacity, and ancillary resources that are integrated with wholesale markets.

3.2.7.4. FY 2011 Smart Grid Capable Electric Vehicle Supply Equipment (EVSE) FOA (as part of Advanced Components and Subsystems)

The DOE issued a FOA (DE-FOA-0000554) in June 2011 on the development of EVSE capable of implementing smart charging of EVs. The objective of this FOA was to develop and make available to the market in three years smart grid-capable EVSE for AC Level 2 charging at residential and commercial sites for half of the current costs of commercially available EVSE with comparable functionalities. The cost-reduction targets for EVSE, once met, will help accelerate the build-out of smart charging infrastructure, leading to increased adoption of electric vehicles. Four awards were announced in December 2011; they are: Delta Products Corporation and Siemens Corporate Research for residential EVSE development; and Eaton Corporation and General Electric for commercial EVSE development. The total public-private investment is expected to be $10.8 million, with the DOE share being $6.8 million.

3.3. Modeling

This section focuses on the capabilities required to model the behavior, performance, and cost of distribution-level smart grid assets and their impacts at all levels of grid operations, from generation to transmission and distribution. Smart grid assets—from DR, distributed generation (DG), and storage, to distribution and feeder automation—can be applied to provide benefits ranging from peak load management, reliability, ancillary services, renewables integration, and carbon management. Modeling the smart grid requires fundamental characterization of the physical aspects of a smart grid in forms suitable for rapid computation and estimation. The physical models range from power flows to customer loads and distributed resources, but also must include the function of communication systems, control systems, and market/incentive structures that enable these assets to form a smart grid. Also required is the ability to portray smart grid performance and economic impacts on both actual and representative segments of the U.S. distribution grid, in context with surrounding bulk generation and transmission systems, market structures, reliability coordination, and utility operations.

3.3.1. Technical Goals and Objectives

1. Make comprehensive smart grid components and operations modeling capabilities available in distribution engineering tools so that smart grid options can be considered on an equal footing with today’s strategies during the system design process.
2. Establish benchmark test cases to validate smart grid models and software tools.
3. Add high-performance computational capability to smart grid models for use in operational controls and decision support tools.
4. Develop the capability to model impacts of smart grid operations on the entire grid.

5. Provide for continuously updating the distribution system model in distribution engineering tools so that they accurately reflect the current configuration, which will be increasingly dynamic as smart grid technology is deployed.
6. Develop and demonstrate techniques for integrating communication network models, wholesale market models, and renewable resource models to form more comprehensive smart grid modeling environments.
7. Support development of open standards for describing distribution systems, customer loads, and smart grid components.

3.3.2. Technical Challenges

Although many power-system modeling tools exist, new modeling capabilities will be needed because of the differences between current power-system technologies and the next-generation, smart-grid approaches. Three key overarching challenges are to:

- Model the engineering characteristics, control, and operation of a wide variety of smart grid assets with sufficient fidelity so that options for the design and configuration of a smart grid can be explored and continue to evolve.
- Incorporate modeling capabilities and costs for smart grid assets in the engineering tools with which the utility industry plans and designs their distribution systems so that smart grid assets can be considered in context with traditional system designs.
- Increase the computational efficiency and speed of smart grid models so that they can serve as the foundation for real-time operational control and decision-support systems.

The technical challenges for modeling a smart grid are considerable, because they involve the capability to model impacts in a variety of dimensions, including:

- smart grid business case and consumers
- capacity and asset utilization
- wholesale markets
- reliability
- environment
- alternative control strategies for distribution, distributed resources, and demand response
- communications network and loss of communication contingencies
- cyber security measures and breaches
- distribution planning and engineering design practices
- generalizing and extrapolating ARRA grant and demonstration project results
- smart grid’s role in context with scenarios for the design and operation of the future grid

3.3.3. Technical Scope

Technical scope for modeling as defined at the June 6, 2012 Smart Grid R&D Discussion Forum is provided below. Modeling may take place in an off-line, planning mode or as part of real-time operations. While both must model effects of smart grid operations, models embedded in real-time operations must be capable of rapid computation, albeit focused on the coming minutes or hours. Conversely, off-line analyses may span time scales of a year or even decades. The sidebar lists other important, general attributes of smart grid models.

Some important attributes of smart grid models are the ability to:

- Explicitly model control strategies and interfaces among control domains
- Flexibly model different smart grid system designs and topologies
- Track all economic impacts on consumers and utility expenses and revenues
- Record time-series histories of all operational and financial impacts.

- **Volt-VAR management -** Modeling capabilities need to be established that will enable the coordinated management of existing and emerging technologies such as tap changers, static VAR compensators (SVCs), cap banks, and real power management of energy storage, demand response, PV, etc. New control strategies are needed for mitigation of high penetrations of PV solar focused on coordination of inverters, fast acting demand response, and storage with existing volt-VAR equipment and controls. Business cases are needed to be developed for options for these mitigation strategies, and for conservation voltage reduction. Key modeling challenges include developing models that accurately represent the internal controls of inverters and constraints on their VAR generation/consumption, dynamic models of inverters and their controls, and faithfully representing individual anti-islanding controls and the network-mediated interactions between anti-islanding controls.

- **Distribution management system -** Modeling capabilities need to be established to better represent DMS functions on feeder topological reconfigurations, control strategies, and existing and emerging utilization strategies for distributed resources and demand response.

- **Fault identification and feeder reconfiguration** - The primary unmet modeling need is the capability to model a variety of existing and new control strategies by which the options for reconfiguration are analyzed, and the optimal configuration selected. Exploration of new control strategies and quantifying their reliability impacts are the primary applications for this capability. Ultimately, options such as providing differentiated reliability services to specific customers and loads need to be developed.

- **Integrated power system with communications network -** Although communication protocols are being defined, there is a lack of standardization and open architecture which extends across multiple smart grid resources that would allow optimized and reliable control of the resource both autonomously and as part of a system.

- **Smart meters** - Modeling capabilities are needed to faithfully emulate the operation of the different types of smart meters, e.g., what data is provided, the precision of the measurements, data compression and correlation, and the latency in communicating this information back to the utility or other third party.

- **Sensors (SCADA, PMUs, etc.) -** High speed telemetry is needed that is sufficient for supervisory (distribution level) control, three phase telemetry, and state estimation. A single device (like a PMU) could be designed to meet 95% of all control and telemetry needs for distribution level smart grid applications.

- **DR and customer behavior** - Need to link demand side simulation tools with distribution and transmission system modeling tools. Develop and analyze various technology penetration scenarios and consider needs of the grid during the transitions. Optimization of DR resources and impacts on voltage and frequency of large DR resources.

- **Dispatchable distributed generation -** Models and capabilities are needed to plan, quantify costs and benefits, and optimize the operation of these resources.

- **Renewable (non-dispatchable) resources -** In addition to general improvements needed to fully model inverter-based equipment, modeling capabilities that need to be established to improve the representation of renewable resources on the distribution system include improved availability of small time-step resource data, ability to create accurate generation profiles from different types of measurement sources and resource configurations, temporal and spatial representation of environmental events such as cloud passage, and protection impacts such as variations in fault current.

- **Dispatchable energy storage -** Multi-objective control algorithms that operate in coordination with other smart grid resources to meet both feeder and local objectives have not been developed or employed. Such objectives must include a means to maximize the overall storage benefit (which also considers the lifetime of the storage system itself).

- **PEV charging** - Analysis of technology penetration scenarios, V2G impacts on the grid and the markets as well as communication scenarios with these resources.

- **Wholesale and retail market operations -** Modeling and simulation of wholesale market operations is fairly advanced while retail market modeling is very limited.

- **Ancillary services -** There are a limited number of facilities that have demonstrated ancillary services provisions at the industrial level. Identification of the resource and capabilities is lacking. At the distribution levels, there is a need to develop stochastic and statistical modeling for large aggregations of small loads. Volt-VAR optimization is also needed to better understand future implications in topology changes in regards to renewable generation, new electronic loads, and electric vehicle charging. Electric vehicles add complexity to the energy balance ancillary service.

- **Microgrids -** Key modeling gaps include dynamic models of generation, especially distributed generation and controls and hardware needed to ensure reliable transition from on-grid to off-grid and vice versa. Additionally, adaptive protection hardware and software schemes are needed for microgrid operation both in the grid-mode and island mode since operating conditions can be quite different. Current protection schemes rely on overcurrent protection, which does factor in benefits offered by communications systems. Advances in the protection area are required due to fast response of distributed generation and microgrids and the coordination that is needed for reliable operation.

- **Hardware in the loop & virtual performance testing -** Virtual performance testing can be performed to reduce the hardware needed for testing and R&D costs. Furthermore, the virtual performance testing can be used to scale up and down the test system. Real-time Data Simulator (RTDS) systems can simulate an interconnection while performing component testing to understand system impacts.

- **Forecasts of load, demand response, price, and renewable -** Modeling capabilities need to be established to consider, within system operations, the various types of forecasts; these capabilities include algorithms and business cases that make use of forecast data to control the behavior of distribution assets, accurate representation of forecasts versus actual demand response, and the impact of assets using forecast data on real-time signals such as pricing.

- **Uncertainty management and quantification -** For adequacy, methodologies need to be developed that allow overall grid adequacy to be calculated, while using distributed and probabilistic and stochastic sources such as solar PV, demand response, and energy storage. For security, statistical characterization of distribution system outages should be developed that include the advanced technologies and controls within the distribution system.

- **Stochastic models of reliability and performance -** Although stochastic models for reliability and performance exist for use with transmission grids, these models are still immature and reside nearly entirely in the research domain for the distribution system. These models need to be adapted for use with power flow solvers in distribution grids; probability distributions for distribution grid variables need to be developed (e.g., renewable generation injections, individual household loads, outage modeling, etc.); and relevant performance metrics for distribution network operations must be defined.

- **Control algorithms** - Some control algorithms are based on heuristics and cannot be applied on a large scale. Many still need to be developed and improved.

3.3.4. Status of Current Development

This section identifies categories of existing modeling tools that *facilitate and are pertinent to analysis* of a smart grid. For each category, we identify the basic use and purpose of that type of tool, summarize its technical capabilities, and briefly describe its role in modeling the smart grid.

The categories used are:

- distribution engineering analysis tools
- dynamic analysis tools
- transient analysis tools
- communication network models
- renewable resource models
- market models
- building models
- research-oriented simulation environments

Examples of common distribution engineering tools:

- WindMil (Milsoft)
- Feederall (ABB)
- PSS Sincal (Siemens)
- CYMDIST (Cyme)
- Analysis Dapper (SKM Systems)
- Distribution Engineering Workstation (EDD)
- Distriview (Aspen)
- Paladin (EDSA)
- PowerFactory (DIgSILENT)
- NEPLAN (BCP Switzerland)
- OpenDSS (EPRI)
- CAPE (Electrocon)

Distribution Engineering Analysis Tools

Traditional distribution engineering analysis tools are *used by utility distribution engineers and planners for engineering design of classical distribution systems*, including, but not limited to, expansion planning, sizing of equipment, project costing, fault current analysis, and protection design.

Examples of distribution engineering tools are listed in the sidebar. Distribution engineering tools primarily model some variation of unbalanced steady-state, 3-phase power flow, in the frequency domain, and with load represented as a real- and reactive-power (P/Q) boundary condition for an instant of time being analyzed. A few also have power quality, flicker, and dynamic analysis capabilities. They are driven from databases used to manage distribution system facilities and assets (automated mapping [AM]/facilities management [FM]/geographic information systems [GIS]). They typically also contain databases of equipment selections.

Distribution engineering tools have the ability to model power flow in traditional distribution systems and components, including:

- *substations* – including step-up and step-down transformers, switches, and distribution buses
- *distribution feeder circuits* – including circuit breakers, switches, overhead lines (grounded and ungrounded), and underground cables (concentric neutral and tape shielded)
- *protective equipment* – including relays, reclosers, fuses, and disconnect switches
- *voltage control devices* – including capacitors (for voltage regulation and power factor correction) and voltage regulators (including compensator settings)
- *secondary systems* – including center-tapped transformers with triplex cables and three-phase transformers with quadraplex cables
- *switches* – installed to cut off or redirect power flow and for load balancing, including circuit breakers, self-protected disconnects, switch gear, group-operated switches (3-pole), and normally open intertie switches
- *distribution transformers* – including three-phase, single-phase, center-tapped, open-delta configurations, as well as other less common configurations

Traditional distribution engineering tools have limited capabilities for modeling smart grid operations. Many have some capability for incorporating distributed induction-, synchronous-, and inverter-based generators including engine generator sets, micro-turbines, wind generators, and PV arrays. They have little or no modeling capability for DR, two-way power flow, distributed storage, or dynamic feeder reconfiguration. They are not designed for simulating the hour-by-hour operation of distribution systems over long time periods (years to decades) required to analyze benefits of smart grid assets and their respective operational strategies. It is also worth noting that the distribution system descriptions used by these models today often lack information on secondary distribution system and customer characteristics that will be needed in the future. These tools also lack the capability to model power electronics and DG dynamics.

Dynamic Analysis Tools

Dynamic analysis tools are primarily *used by utilities, ISOs, and RTOs for transmission system engineering and planning*, including offline studies of dynamic stability issues and the production of nomograms describing stability limits. They primarily model the grid's voltage and frequency response as a function of the behaviors of the generators. Examples of models used for dynamic stability analysis are listed in the sidebar. (Two of these models are distribution engineering tools).

Example tools with dynamic analysis capabilities:

- PSLF (GE)
- PSSE (Siemens)
- PowerFactory (DIgSILENT)
- NEPLAN (BCP Switzerland)

These tools have limited built-in abilities to model smart grid capabilities. They do have an important near-term role to play in analyzing the impacts and stability benefits for the bulk grid from the under-frequency and under-voltage load shedding made possible by a smart grid. They also have an important near-term role in modeling frequency and voltage in outage scenarios as a boundary condition for detailed smart grid models. Tools that have distribution engineering capabilities may be particularly useful in modeling microgrids where the voltage and frequency are likely to experience larger variations.

Transient Analysis Tools

Transient analysis tools are primarily *used by engineers in the utility, vendor, and research communities to design interconnection standards, automatic disconnect gear, and inverters for distributed energy resources* (generation and storage) and to analyze their impacts on distribution system protection schemes. Some examples of these models are listed in the sidebar. These tools primarily model sub-cycle voltage and frequency response, switching transients, and the power electronics and high-speed data acquisition on systems used for interconnection.

Examples of models that have transient analysis capabilities:

- PSCad (Manitoba HVDC Research)
- SimPowerSystems (The Mathworks)

Examples of communication network models:

- Qualnet
- Opnet
- Washington State University
- IT network companies: IBM, Cisco, Google, AT&T, etc.

Communication Network Models

Communication network models are *used by information technology companies and national defense researchers* *and application developers for communication network design, engineering, and planning*. Some examples appear in the sidebar. They are used to model network characteristics such as topology, traffic volumes, latency, redundancy, and the effects of disruption, including cyber attacks. They have not generally been integrated with power system models although, in one example, Washington State University has a model integrating phasor measurement units and their data network communication systems. Research has also been conducted on cyber security for SCADA systems at Idaho National Laboratory using Qualnet and Opnet.

Renewable Resource Models

Renewable resource models are *used by utility planners and operators, researchers, and investors to understand resource availability and energy output for wind and solar generation*. These models primarily estimate the energy production potential on average years and provide economic analysis of renewable generation. Some examples appear in the sidebar. These models currently have little if any integration with distribution engineering tools or smart grid simulations.

Examples of renewable resource models:

- LEAP
- BCHP Screening Tool
- energyPRO
- Solar Advisor Model (SAM)
- TRNSYS16

Market Models

Market models are *designed for use by regulatory institutions to study market design and consumer impact issues, by transmission companies and market operators to analyze system and market performance, and by generation companies to analyze corporate strategies*. Some organizations developing market models are:

- *Iowa State University* – AMES is an agent-based model of power producers, load-serving entities, and an ISO in a wholesale power market over a realistically rendered AC transmission grid. It currently implements the market design outlined in the business practices manuals of the Midwest Independent System Operator (MISO).
- *Argonne National Laboratory* – The Electricity Market Complex Adaptive System (EMCAS) model simulates the behavior of restructured power market participants using an agent-based complex adaptive systems approach over six decision levels, ranging from hourly dispatch to long-term planning. At each level, certain decisions are made, including determining electricity consumption (customers), unit commitment (generation companies), bilateral contracts (generation and load-serving companies), and unit dispatch (power system operators). It has been used to study restructuring issues in the U.S., Europe, and Asia.
- *Cornell University* – Experimental economics and decision research studies using human subjects interacting with power flow simulation and markets. Used to study market design and human decision making with actual financial incentives as motivation.
- *Danish Technical University* – Studies NORDPOOL markets, particularly focused on the interactions between Denmark’s wind resources and Norway’s hydropower resources.

Building Models

Building models are *used primarily by researchers on energy conservation design practices and technologies, and by developers of energy codes and standards, to simulate the time-series thermal performance of building envelopes and heating/ventilating/air conditioning (HVAC) systems*. These tools explicitly include the effects of other end-use loads like lighting, appliances, and electronic equipment on heating and cooling to predict whole building loads; however, these other end uses are input assumptions rather than model predictions.

Building models such as DOE-2 and BLAST operate at hourly time steps. These tools embed traditional HVAC control schemes, and so are not conducive to the addition of user-specified controls, such as for DR. The latest generation model is EnergyPlus. Extensions for it have been developed by the NREL and LBNL that allow users to specify DR control strategies, for example. Full thermal system transient modeling tools such as TRNSYS can be used to model arbitrarily complex mechanical systems and controls. There is little or no integration of these models and smart grid. They are best suited to developing DR control strategies for large commercial buildings with complex HVAC systems. They are not well suited to modeling entire populations of buildings.

Research-Oriented Simulation Environments

Research-oriented simulation environments are *used by researchers, technology developers, and policy analysts for analysis of distribution and smart grid assets, controls, and operational strategies*. Their primary purpose is for exploring technical and economic potential of smart grids, developing and analyzing operational strategies, control algorithms, market/incentive structures, and communication requirements.

Examples of research-oriented tools with user-extensible simulation environments:

- GridLAB-D (PNNL)
- OpenDSS (EPRI)
- Distributed Engineering Workstation (EDD)
- PowerFactory (DIgSILENT)
- NEPLAN (BCP Switzerland)
- PSCad (Manitoba HVDC Research)
- The Mathworks (SimPowerSystems)

These research tools are fundamentally characterized by being extensible—that is, users can add their own component models, control algorithms, and dispatch strategies to explore options for a smart grid. Therefore, they serve an important role in bridging the gap until distribution engineering tools integrate more comprehensive smart grid modeling capabilities.

Some examples of such environments are listed in the sidebar above. All have basic power flow capabilities; all but the last two focus on distribution system operations. The first two models listed are unique because they are open-source projects, giving users full access to modify and improve them, and because they are oriented toward simulating annual time-series. These two models are summarized in the following boxes.

OpenDSS is receiving substantial EPRI investment:

- Analysis of both system planning and real-time operations.
- Several built-in solution modes, including:
  - power flow as a real-time snapshot
  - cumulative daily and yearly power flows
  - harmonics, dynamics, & fault studies
- Experienced software developers can customize OpenDSS by:
  - downloading source code
  - writing software controls through a component interface
  - developing DLLs

GridLAB-D has received substantial DOE investment to integrate distribution, loads, and smart grid assets:

- Real-time price retail market
- Most distribution components
- Populations of buildings
- Voltage-dependent, weather-driven, end-use loads
- Actual feeders (importing some vendor formats)
- Statistically representative feeder prototypes
- DR
- CVR and volt-VAR control
- DG & storage, inverters
- PV, wind turbines

3.3.5. Technical Task Descriptions

The following technical tasks and associated milestones, measures of success, and timeframe were developed at the Smart Grid R&D Discussion Forum held on June 6, 2012.

1. **Integrated Power System with Communications Network** (tied with #2 on vote count)
   Gaps: Modeling the effects of latency, traffic volumes, availability and integrity of data (data dropouts), and communication media on power system planning, operations, and reliability. The gaps include protocol conversion, cyber security delays, etc.

   Milestones:
   - Review available communication systems developed and practiced by other industries, and adapt them for integration with power system models.
   - Obtain data from priority communication protocols (defined by the SGIP and used in the field) to estimate the effects.
   - Develop interoperable interfaces between communication system and power system models.

   Measures of Success:
   - A framework to facilitate an open, scalable, interoperable, and integrated system model that enables better understanding of interdependency between communication and power system models.
   - Put into practical use by smart grid community (industry, multiple vendors, etc.).

   Timeframe: 3-5 years

   Level of Effort: High

2. **Advanced Control Algorithms** (tied with #1 on vote count)

   Gaps: Develop different M/S platforms for varying time scales to help develop, test, and validate different control algorithms (non-prescriptive but user specifiable) that perform smart grid functions. Real-Time Digital Simulators are an example of such a platform that covers electromagnetic transient phenomena. The gaps include both component and system controls.

   Milestones:
   - Conduct a scoping study on existing platforms for gaps.
   - Prioritize platform development for different ranges of time scales.
   - Develop platform(s).

   Measure of Success:
   - Consistent and uniform simulation results.

   Timeframe: 3-5 years

3. **Renewable (Non-dispatchable) Resources**

   Gaps: In addition to general improvements needed to fully model real and reactive power (inverter-based equipment), modeling capabilities that need to be established to improve the representation of renewable resources on the distribution system include improved availability of small time-step resource data, ability to create accurate generation profiles from different types of measurement sources and resource configurations, temporal and spatial representation of environmental events such as cloud passage, and protection impacts such as variations in fault current.

   Milestones:
   - Validate the first-generation M/S results of cloud transient effects on PV power output variability.
   - Integrate existing capabilities into the smart grid modeling environment.

   Measures of Success:
   - Conduct first ever demonstration with validation against field results.
   - Model PV controls for mitigation of impacts on high saturation of PV on distribution feeders (with electric vehicles, energy storage).

   Timeframe: 1-3 years

4. **Interoperability among Formerly Independent (Disparate) Models** (tied with #5 on vote count)

   Gaps: Interoperability among data that drives models; interoperability of model components among models; and integration of models. A scoping study is needed to define what is required (what questions need to be answered).

5. **Test Cases for Availability of Measured Data for Model Verification and Validation (V&V), Modeling Load Profiles (e.g., Industrial...), etc.** (tied with #4 on vote count) No discussion on this capability was possible because of time constraints.

3.3.6. Milestones

The milestones are included in each Task description in section 3.3.5.

3.3.7. FY 2012 Accomplishments

Further advances in the GridLAB-D simulation tool by PNNL were made in FY 2012. These included development and implementation of a dual-objective control framework to manage dual benefit streams from a smart grid technology for building a viable business case. The dual-objective controls developed in GridLAB-D include: managing demand response for the objectives of peak shaving and ramping services; managing energy storage for the objectives of peak shaving and voltage regulation; and managing PEV charging for the objectives of peak shaving and ramping services.

ANL has developed a publicly available tool for analyzing and designing dynamic pricing programs. This Excel-based tool allows utilities to analyze price elasticity of electricity demand from dynamic pricing (ToU and/or CPP) pilots, and to project changes in electricity loads as a function of electricity prices and temperatures as specified by utilities. The built-in functions of the tool further allow utilities to use pilot program results to design future dynamic pricing programs to meet utility-defined objectives for peak load reduction and revenue, under a given set of temperatures. This tool is targeted for use by electric utilities and public utility commissioners in designing and evaluating dynamic pricing programs for large-scale implementation beyond the pilot program stage.

The Program convened the Smart Grid R&D Discussion Forum on June 6 in San Diego, California, immediately before the 2012 Peer Review meeting to seek input from people attending the peer review meeting on select R&D areas. Among them was modeling & simulation. Prioritized modeling & simulation capabilities in need of further R&D identified from the Forum are listed in section 3.3.5.

3.4. Analysis

This section presents goals, challenges, and activities proposed for the Analysis topic of the Smart Grid R&D plan as organized by the five pillars of smart grid value streams: capacity, power quality and reliability, energy efficiency, operational efficiency, and clean technology. An additional category, economic/business environment, is added to capture investigation of value propositions and the incentives to bring about deployment of smart grid capabilities. The analysis activities include a foundational/crosscutting section to capture the fundamental attributes of smart grid that cut across the various categories.

3.4.1. Technical Goals and Objectives

The Analysis plan attempts to address the important questions the nation faces in moving forward with smart grid decisions and related deployments. This section presents the goals that influence the selection of analysis activities.

- Foundational/Crosscutting Goals
    - Assess progress of smart grid deployments and investments.
    - Effective cyber security and information privacy practices accepted by industry.
- Capacity Goals
    - Understand the impact of different smart grid designs and deployments on the capacity available to the grid.
    - Understand the influence of dynamic prices, load control, or other demand response processes on capacity availability at critical periods.
    - Characterize the impact of distribution automation on availability and functionality of distributed resources.
    - Understand the influence of high-penetration distributed generation and local voltage control on capacity availability.
    - Understand impact of smart grid on the mix, size, and location of future generation and storage options.
- Power Quality & Reliability (PQR) Goals
    - Provide an analytic basis for the delivery of appropriate levels of PQR at the various levels of "smart" distribution infrastructure and end-use systems, recognizing the differentiated costs and benefits.
    - Characterize the maintenance of desirable PQR in the face of countervailing forces and policy objectives (such as high renewable resources penetration, active markets, high equipment utilization, limits to supply chain expansion, growing electricity demand—including transportation electrification) and their dynamic interactions.
    - Create opportunities to capture the potential of distributed resources (including microgrids, more localized electricity hubs, and building systems) for better targeting of PQR.
    - Assess the impact of a smart grid on the number, duration, and extent of electricity outages, including cascading events.
- Energy Efficiency Goals: enable incorporation of energy efficiency approaches
    - Apply information gained from DR programs to encourage end-use conservation.
    - Leverage measurement and verification (M&V) for efficiency programs.
    - Conserve energy by using voltage reduction and advanced volt/VAR control.
    - Evaluate the energy efficiency impact of energy management devices in consumer facilities.

- Operational Efficiency Goals
    - Effectively integrate DER and distribution automation to provide ancillary services and optimize asset utilization.
    - Reduce cost for wholesale and retail operations by efficient coordination of supply-side and demand-side resources.
    - Use measurements, diagnostics, and automation to reduce maintenance cost and the impact of failures.
- Clean Technology Goals: establish smart grid as an enabler to mitigate environmental impact, particularly CO_2
    - Enable high penetration of renewable energy resources throughout the system, particularly at the distribution system level.
    - Enable PEV benefits for emissions reduction and energy storage.
    - Manage environmental consequences of load growth.
- Economic/Business Environment Goals: economic/business value proposition for smart grid investments and deployments
    - Articulate and substantiate values/benefits for smart grid functionality for all smart grid applications, including the value proposition for storage in system operations.
    - Determine appropriate allocation of smart grid benefits to electric service providers, consumers, and society.

3.4.2. Technical Challenges

The challenges for the analysis aspects of smart grid fall into the categories of data challenges, modeling and simulation challenges, and socio-economic challenges.

- Data challenges
    - Accessibility, sufficiency, and management of large data sets for analysis and diagnostics.
    - Coordination with existing and emerging data sets related to smart grid, such as those gathered through international efforts and the Smart Grid Information Clearinghouse project. Common standards and formats for data are required.
    - Diversity and selection of regions for scenario development.
    - Different scales associated with data involved in the analyses:
        - Geographic: local, regional, national; and
        - Time dynamics: physical transients, operations, planning horizons.
- Technology modeling and simulation challenges
    - Variability, variety, and technical immaturity of potential DER mixtures.
    - Inexperience with distributed control theory of smart grid system operations.
    - Inexperience with aggregated DER behavior at systemic level:
        - Stability and reliability are multidimensional and not easily aggregated or summarized.

    - Complex interactions of power, communications, and other national infrastructures.
    - Complexity of modeling many nodes of generation/storage accompanying dynamic and automated changes in grid operation.
- Socio-economic challenges
    - Customer acceptance and behavior regarding smart grid capabilities.
    - Effective incentives for providers and end users are hard to assess.
    - Complex landscape for coordinating regulatory policy with market/business drivers.
    - Actual savings and intangible benefits can be hard to quantify and assign.
    - Cyber security vulnerabilities and risks, especially systemic impacts.
    - Complexity and variability of each state regulating smart grid implementation and cost recovery.

3.4.3. Technical Scope

The *Analysis* section focuses on investigating the important questions that surround potential capabilities, deployment, and performance scenarios of related devices and systems (anticipating the internal and external benefits), and the path (economics, business plans, and regulatory/policy environment) to achieving smart grid objectives at the distribution level. In addition, questions concerning the impacts/benefits of distribution level capabilities on the higher, bulk energy levels of the system fall within this scope. The analysis tasks include the articulation of questions to be addressed, the structure and approach for addressing each question, as well as the answers and insights that are gained from the analysis of these questions.

Analysis activities are interdependent with the methods and tools that are the subject of the *Modeling* section. The analysis activities also coordinate with the *Evaluation & Demonstrations* section, particularly in use of information gained from ARRA-funded smart grid deployments and demonstrations. Significant knowledge can be gained through analyzing the performance of these projects in terms of what they accomplish, as well as what technical barriers and challenges will continue to exist but must be overcome for a successful smart grid transformation. Analyses of these projects and their results will thus provide critical information in identifying gap areas in need of longer-term R&D. These gap areas will help guide the Smart Grid R&D Program in making base-program investments in smart grid technologies and systems.

3.4.4. Status of Current Development

3.4.4.1. Foundational/Crosscutting Analysis

Several analysis items are so fundamental to smart grid capabilities that they cut across many or all of the analysis topic areas. The various states of development for such items are described in the following bullet items:

- Smart grid deployment assessment: EISA 2007 directs the Secretary of Energy to provide a biennial status report to Congress. The 2010 Smart Grid System Report was published in February 2012.[24]
- Cyber security, information privacy, and interoperability: DOE, FERC, NIST, and industry are investigating cyber security issues on many fronts. Awareness is heightened; however, best practices and procedures to address cyber security issues are only emerging.
- Smart grid impacts on system planning: Smart grid capabilities have had little impact on power system operations thus far. There is a long history and inertia to the best practices for planning that will take time to change.
- Consumer acceptance: Smart grid pilot projects and some advanced metering implementations have provided insight into human behavior for services such as price-responsive DR programs. The ARRA investment grants and demonstrations provide opportunities to understand consumer interaction at a far grander scale.
- Adequacy and maintenance of data for analysis: The DOE has established the data capture needs and processes for the ARRA smart grid projects. The description and format of the data have been specified so that researchers can understand and reasonably use it in their investigations. Progress is being tracked on the following impacts and benefits: job creation, peak load reduction, system energy efficiency, power quality and reliability, O&M, and consumer energy and cost savings. Data from ARRA smart grid projects are collected in four online databases: the Smart Grid Data Hub (build and impact metrics), FederalReporting.gov (jobs and financial data), VIPERS (invoicing system), and SIPRIS (project execution data and other reporting; SIPRIS is for SGIG projects only). Coordination is also needed with data collection and management across DOE efforts including the ARRA programs, the Smart Grid Information Clearinghouse, the Energy Information Administration (EIA), and non-government smart grid data collection programs.
- Distribution system performance data: EIA collects some information related to the distribution system, particularly reliability indices. The ARRA-funded projects will collect information related to smart grid deployments, which may shed new light on existing power system operational performance. This may influence new metric definitions related to distribution system performance for measurement.

3.4.4.2. Capacity Analysis

A smart grid provides increased grid capacity through facilitation of distributed and renewable generation resources participation, dynamic DR based on capacity needs and constraints, and distribution infrastructure reconfiguration (T&D automation) that improves the use of existing assets. Analysis of capacity issues involves the study of how much power (or power savings) could be facilitated by a smart grid. While a smart grid by itself does not create capacity, the communications system makes larger amounts of demand response from end-users feasible. Smart grid also improves the integration of distributed generation or storage at end-user locations

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[24] Available at http://energy.gov/oe/articles/2010-smart-grid-system-report-available-february-2012.

into the grid to provide additional capacity. Besides generation capacity, transmission and distribution capacity is of issue here. Inadequate T&D capacity may be a more critical problem. Smart grid can improve asset utilization, and thereby avoid the need for new capacity.

- Demand response analyses
    - FERC: "A National Assessment of Demand Response Potential," June 2009,[25] "National Action Plan on Demand Response," June 2010,[26] and Implementation Proposal for the National Action Plan on Demand Response, July 2011.[27]
    - EPRI, "Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S.: (2010-2030)," 1016987, EPRI, Palo Alto, CA: January 2009.[28]
    - LBNL, "Estimating Demand Response Potential among Large Commercial and Industrial Customers: A Scoping Study," January 2007.[29]
- DER analyses
    - Renewable Electricity Futures study.[30]
    - Renewable Systems Interconnection: Comprehensive Summary.[31]

3.4.4.3. Power Quality & Reliability Analysis

Smart grid concepts rest heavily on the notion that North American PQR needs to be improved significantly to support the requirements of a *digital society*, as well as to improve *emergency response*, *convenience*, and *general productivity*. Much less clear are the desirable levels of PQR, both universally (at the substation) and locally (at the meter, the building circuit, the end-use device, and within the device, i.e., to serve its various functions). The costs and benefits of PQR, as well as the desirable equipment and market mechanisms for providing it, need study. Further, little is known of the impact to system stability as smart grid technology and market signals emerge and reliance on information networks becomes more pervasive. Thus, models and analyses are an integral part of understanding how smart grid needs to evolve to best achieve the desired goals.

A considerable body of literature exists on PQR, although it is skewed heavily towards studies of headline regional and international outages, which represent a small fraction of the overall PQR problem. Further, virtually all technical literature in the area addresses defining PQR problems

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[25] Available at http://www.ferc.gov/industries/electric/indus-act/demand-response/dr-potential.asp.

[26] Available at http://www.ferc.gov/legal/staff-reports/06-17-10-demand-response.pdf.

[27] Available at http://www.ferc.gov/legal/staff-reports/07-11-dr-action-plan.pdf.

[28] Available at http://mydocs.epri.com/docs/public/000000000001016987.pdf.

[29] Available at http://eetd.lbl.gov/ea/emp/reports/61498.pdf.

[30] A summary presentation is available at http://www1.eere.energy.gov/solar/review_meeting/pdfs/prm2010_plenary_ren%20elec%20futures_baldwin.pdf.

[31] Available at http://www.e2rg.com/reports.

and establishing and meeting performance standards. Questions regarding the economics, public policy, standards, or analysis of the PQR requirements of end-uses remain largely unexplored.

- CYME, Milsoft, μGRD, and other power flow tools have been developed and extended to consider PQR.
- Classic outage studies include analysis of the Aug. 14, 2003, U.S.-Canada Blackout[32] and the 1965 and 1977 New York blackouts.[33]
- More recent analysis of delivered reliability includes the LaCommare & Eto review of estimated outage costs, including prior work by EPRI and others[34] and the same authors' review of state reliability filings.[35]
- Reviews of emerging smart grid technology include: EPRI's "Integrating New and Emerging Technologies into the California Smart Grid Infrastructure," CEC 500-2008-047, September 2008.[36]
- A recent discussion of the business implications of strict PQR requirements for the digital economy is: Robert Galvin, Kurt Yeager, and Jay Stuller, *Perfect Power: How the Microgrid Revolution Will Unleash Cleaner, Greener, and More Abundant Energy*, McGraw Hill, New York, 2009.

3.4.4.4. Energy Efficiency Analysis

The ability to sense, collect, and report information related to electricity operations is a smart grid trademark that lends itself to enhancing energy efficiency objectives. By providing operators and end-users with performance information, energy inefficient problems can be diagnosed, expectations can be monitored, and habits can be changed. This area focuses on energy efficiency from an end-use perspective, while operational efficiency includes efficiencies in the electricity delivery infrastructure (e.g., line losses).

The analysis of smart grid impacts on energy efficiency is in its infancy. While there is a history of analysis associated with collecting information to understand and diagnose equipment and building energy inefficiencies, being able to use additional information gained from smart grid deployment expands the reach and scale of such analysis to new levels. Using smart grid capabilities to encourage and support energy efficiency goals can be subtle. A few reports extend analysis into this area.

- Pratt, R. G., et al., "The Smart Grid: An Estimation of the Energy and CO_2 Benefit," December 2009.

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[32] Available at https://reports.energy.gov/.

[33] Available at http://blackout.gmu.edu/archive/a_1965.html and http://blackout.gmu.edu/archive/a_1977.html, respectively.

[34] Available at http://eetd.lbl.gov/ea/emp/reports/58164.pdf.

[35] Available at http://eetd.lbl.gov/ea/emp/reports/lbnl1092e-puc-reliability-data.pdf.

[36] Available at http://www.energy.ca.gov/2008publications/CEC-500-2008-047/CEC-500-2008-047.PDF.

- "The Green Grid: Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid," EPRI-1016905, Electric Power Research Institute, Palo Alto, California, 2008.
- Hledik, R., "How Green Is the Smart Grid?" *The Electricity Journal*, 2009, 22(3):29-41.

3.4.4.5. Operational Efficiency Analysis

Transmission system balancing authorities and local distribution system operators use sophisticated planning, EMS, and power scheduling technologies to project required demand, monitor margin of available supply side resources, and control system challenges to stable operation. The entire process rests on the requirement to match instantaneous demand with sufficient supply-side resource. Determination and supply of adequate additional resources to cover contingencies (lumped here as ancillary services) is a complex and vital operational necessity. Smart grid capabilities can have a strong impact on efficiently operating the power system.

The relationship of ancillary services to adequate power reserves (capacity) and minimum acceptable power quality requirements (typically voltage and frequency bands) is so interdependent that analysis of R&D for operational efficiency, capacity, and PQR will often overlap. Close coordination of effort in these three analysis areas should be an ongoing part of R&D planning integration.

Quantification and documentation of required reserve margins and markets for generators offering ancillary services is well established. NERC was formed to bring international North American standardization to these practices. NERC and regional reliability councils will be indispensable partners in analyzing the use of smart grid-enabled, demand-side resources as ancillary service providers. NERC and the industry in general are just beginning to assess how smart grid capabilities will influence local and regional transmission operating processes. The impact of distribution system advancements (including the engagement of DER) on efficient T&D system operations has been investigated in a preliminary way in the following studies:

- PNNL, "Using Electric Vehicles to Meet Balancing Requirements Associated with Wind Power," PNNL-20501, July 2011.
- National Energy Technology Laboratory, "Electric Power System Asset Optimization," DOE/NETL-430/061110, March 2011.
- W. S. Baer, B. Fulton, S. Mahnovski, "Estimating the Benefits of the GridWise Initiative," RAND report, May 2004.

3.4.4.6. Clean Technology Analysis

One of the most significant benefits of the next-generation smart grid is the flexibility to support high penetration of renewable energy resources. These resources have the potential to provide clean energy to consumers and to reduce CO_2 emissions.

The electric power and end-user automation industries are now actively engaged in the advancement of smart grid and the integration of clean energy technologies. Before the last decade, most deployments of renewable resources were by consumers and were on a small scale at the distribution level. In this last decade, we have seen new large-scale deployments of both wind and concentrated solar power, primarily at the transmission level. There have also been a limited number of utility-scale deployments of PV. At the distribution level, however, consumer deployments of PV are still the norm. There have been major advancements in technologies that allow integration of renewable resources with the distribution grid, including grid-tied inverters. These technologies are fairly mature. However, few places in the world (Denmark being one) have confronted high penetration of renewable resources. The effective management of high-penetration, non-dispatchable, renewable resources using smart grid capabilities, particularly at the distribution level, remains largely unknown and therefore is of major concern.

- National Energy Technology Laboratory, "Environmental Impacts of Smart Grid," DOE/NETL-2010/1428, January 2011.

3.4.4.7. Economic/Business Environment Analysis

A great deal of excitement has surrounded potential economic windfalls from the deployment of a smart grid. Further investigation reveals regulatory and business uncertainty that is impeding the development of smart grid commerce. Analysis is immediately required to help inform national policy makers (both legislative and regulatory) on how to create a vibrant, level commercial playing field that is consistent throughout a national smart grid.

Although there is significant academic research on energy markets and demand-side management, regulatory and business model barriers must be overcome for smart grid to reach its full potential. While many of the problems have been identified, as yet no concerted effort has been made to fund solutions and/or identify who will confront the regulatory barriers to permit the development of new business models for a smart grid.

- "Estimating the Costs and Benefits of the Smart Grid," EPRI-1022519, Electric Power Research Institute, Palo Alto, California, 2011.
- "McKinsey on Smart Grid," McKinsey & Company, Number 1, Summer 2010.
- Brattle Group, et al., "A National Assessment of Demand Response Potential," Staff Report to the FERC, June 2009.
- ISO/RTO Council, "2009 State of the Markets Report."

3.4.5. Technical Task Descriptions

The technical analysis tasks for the strategic value streams of smart grid are listed below.

3.4.5.1. Foundational/Crosscutting Analysis

- Assess progress of smart grid deployments and investments.
- Understand the issues and potential remedies to support effective cyber security, information privacy, and interoperability practices and their acceptance by industry. Investigate ways to measure the cost/benefit of steps to address or improve the situation in these areas.
- Analyze the ramifications of smart grid capabilities on distribution, transmission, and generation planning.

- Investigate issues and propose mechanisms to ensure sufficient data are collected to support analyses, and to ensure effective access and use of measurement data collected as a result of smart grid implementations and experiences, including those supported by ARRA funding. Research appropriate mechanisms to coordinate and manage such large datasets.
- Collect and disseminate unbiased data on performance of the national distribution system.

3.4.5.2. Capacity Analysis

- Analyze the potential capacity, benefits, and issues involved in smart grid-enabled DR.
- Analyze localized capacity issues that can be helped by smart grid (distribution congestion, local load growth, outages, mobile PEV capacity) and the potential for a locational marginal price as a self-optimizing incentive to engage these resources.
- Analyze capacity shifting through end-use DR and distributed generation and storage in conjunction with building EMS and the smart grid.
- Analyze impacts of PEV interactions with the smart grid.
- Analyze long-term change in generation and T&D capacity use due to smart grid.

3.4.5.3. Power Quality & Reliability Analysis

- Available PQR data are not sufficient for effective policymaking; widespread data collection, archiving, and analysis are needed.
- Analysis of the costs and benefits of PQR as well as the desirable equipment and market mechanisms for providing it must be performed.
- Little is known about the actual PQR requirements of various end-uses and how loads might be disaggregated by their PQR needs.
- Potential provision of ancillary services locally, e.g., voltage support, will require market design, including analysis of consequences of inadequate supply, e.g., market power.
- The impact to local and regional system stability as the penetration of smart grid technology and market signals grows needs analysis, especially as reliance on information networks becomes more pervasive.
- Cyber security is intimately related to PQR, and analysis of the former will involve consideration of the latter.
- Smart grid implications to the interactions and dependencies between the electric infrastructure, the communications networks used in smart grid deployments, and other infrastructures (gas, water, transportation, etc.) are critical for normal and emergency support to our society.
- PQR is a central feature of many, if not all, of the microgrid demonstrations underway in the U.S. and internationally. Review of experience with these aspects is required.

3.4.5.4. Energy Efficiency Analysis

- Better understand end-user behavior and motivation for energy efficiency program administration and implementation with regard to related smart grid capabilities.

- Technology contributions have been considered in isolation. Study the synergistic aspects of combining technologies for energy efficiency contributions. For example, DR technology or PEV integration might also provide feedback to the end user to improve energy efficiency.
- Analyze the effectiveness of various diagnostic techniques based on information likely to come back from DR and advanced metering programs. What data are sufficient to support basic diagnostics, and what is the most important additional information that can improve diagnostics? Evaluate localized diagnostic approaches with remote diagnostic services.
- Study scenarios for smart grid deployment (time and cost/benefit) to achieve energy efficiency.
- Examine the business and regulatory policy issues (money, risk, incentives) that if addressed, can help achieve greater energy efficiency with smart grid technology investments.
- What are the reasonable levels of penetration of smart grid capabilities to achieve energy efficiency over time?

3.4.5.5. Operational Efficiency Analysis

- Ancillary services cover a number of contingencies. What kind and size of ancillary services to be potentially met with demand side resources will scale appropriately? What resource characteristics or combinations are needed for practical mitigation of supply-side resource inadequacy: response rates, duration of availability, capacity and available energy, VAR conditioning, transient ride-through capability, and so forth?
- For specific demand-side power resource technologies operating as local and exporting to distribution grid power devices (e.g., PV, combined heat and power prime mover, grid interactive PEVs, and others), investigate distribution system operational benefit and economic valuation methodologies. For instance, determine methods to quantify system benefit and value that accrues to others on the same feeder or the system as a whole for voltage support, phase angle correction, transformer longevity, etc.
- Distributed generation resources with variable output and potentially high penetration rates (PV, wind) will add new ancillary power needs. What is the effectiveness and efficiency of using demand management resources to enable variable generation additions to the system?
- Investigate ability to use meter and distribution system information to diagnose key system equipment maintenance needs and imminent failure potential.
- Investigate ability to use distribution system information to identify and report specific failure mode, location, and concurrent subsequent equipment failures for distribution-level loss of load incidents.

3.4.5.6. Clean Technology Analysis

- Can DER provide support to enable the integration of variable energy from renewable resources (e.g., fast scheduled energy and ancillary services)?

- How can T&D automation through monitoring and reconfiguration better enable the integration of renewable variable energy resources?
- How will the deployment of high-penetration renewable energy resources impact power system stability (also see PQR section above)?
- How can DER and T&D automation facilitate the high penetration of PEVs? What are the environmental benefits?
- What is the impact of PEV penetration on the ability to address high penetration of renewable resources?
- How can smart grid capabilities help achieve and adapt toward an optimal mix of renewable and non-renewable resources to meet our energy needs?
- How does the effective integration of clean technology change in various areas of the country?

3.4.5.7. Economic/Business Environment Analysis

- Examine the business and regulatory policy issues (money, risk, incentives) that, if addressed, can help achieve greater consumer participation.
- Analyze the effectiveness of various business models. Investigate scenarios for smart grid deployment (time and cost/benefit) to achieve sustainable businesses. What are the savings and intangible benefits associated with smart grid? To whom do these benefits accrue?
- Develop various market designs (urban vs. suburban vs. rural). Evaluate their benefits and assess potential risks to consumer acceptance.
- Regional energy markets have been considered in isolation. Study the synergistic aspects of a national policy and the effect of demand response deployment on regional electricity prices.

3.4.6. Milestones

The milestones for each analysis area discussed above are presented below. The timeframes for completion are indicated as near (1-2 years), mid (3-4 years), long (5 years and beyond), and ongoing (analysis on the same topic expected periodically, such as tracking deployment progress).

Near Term (1-2 years)

- Support effective cyber security, information privacy, and interoperability practices.
- Analyze the PQR risks posed by cyber vulnerability.
- Support T&D system failure and maintenance diagnostics using smart grid information.
- Analyze the effectiveness of various smart grid business models.
- Analyze PEV capacity interactions with smart grid.

Mid Term (2-3 years)

- Analyze the ramifications of smart grid on T&D and generation planning.
- Analyze localized capacity issues (distribution grid congestion, behind-the-meter capacity impacts) and use of locational marginal price incentives at distribution level.
- Analyze and categorize the PQR requirements of end uses and intra-end-use loads.
- Analyze the PQR lessons of ARRA demonstrations and investment grants.
- Analyze scenarios for smart grid deployment (time and cost/benefit) and the business and regulatory policy issues to achieve energy efficiency.
- Characterize variable DER (e.g., renewable resources, PEV charging) accommodation using demand-side resources.
- Analyze the impact of T&D automation on integrating high penetration of variable renewable resources with coordinated use of DER.
- Analyze potential of PEV charging and discharging to enable high penetration of variable renewable resources.
- Develop various retail market designs (urban vs. suburban vs. rural), and evaluate their benefits and assess potential risks to consumer acceptance.

Long Term (5+ years)

- Analyze long-term infrastructure changes in generation, transmission, and distribution due to smart grid.
- Analyze smart grid implications to the interactions and dependencies between the electric infrastructure, the communications networks, and other infrastructures (gas, water, transportation, etc.).
- Determine effectiveness of various diagnostic techniques using field information from DR and advanced metering.
- Characterize DER use in provision of ancillary services.
- Develop an analysis framework for review of optimal mix of renewable and other resources to meet the nation’s energy needs using smart grid capabilities.

Ongoing

- Report progress of smart grid deployments.
- Analyze end-user behavior and acceptance of demand response, on-site generation, PEVs, and storage.
- Estimate costs and benefits of PQR.
- Examine the PQR consequences of upcoming system changes: load growth (including EVs), high renewable resources penetration, restricted supply expansion, etc.
- Inform policy makers of savings and intangible benefits associated with smart grid and to whom these benefits may accrue.

3.4.7. FY 2012 Accomplishments

The DOE has established the data capture needs and processes for projects supported under the ARRA SGIG and Regional Demonstrations Program. The description and format of the data have been specified so that researchers can understand and reasonably use it in their investigations. The DOE Recovery Act Smart Grid Progress Report (July 2012)[37] provides a summary of the SGIG program's progress, initial accomplishments, and next steps. As the projects gather more information, further analysis of results, lessons learned, impacts, and benefits will be made in the following areas:

- Peak demand and electricity consumption reductions from AMI, customer systems, and time-based rate programs
- Operational improvements from AMI
- Reliability improvements from automating distribution systems
- Energy efficiency improvements from advanced Volt/VAR controls in distribution systems
- Efficiency and reliability improvements from applications of synchrophasor technologies in electric transmission systems.

The DOE is part of the International Smart Grid Action Network (ISGAN), a multilateral mechanism for governments to collaborate with each other and other stakeholders on advancing the development and deployment of smart grids worldwide. ISGAN was established as a task-shared International Energy Agency (IEA) Implementing Agreement in 2011. As of this report date, six tasks (or Annexes) have been established. The DOE is leading Annex 1 on building the Global Smart Grid Inventory of projects, which completed an analysis report on smart grid drivers and technologies by country, economies, and continent in September 2012. Other Annexes pertaining to *Analysis* are Annex 2: Smart Grid Case Studies and Annex 3: Benefit-Cast Analyses and Toolkits, both of which the DOE is participating in. These Annexes are collecting smart grid project data/information and analyzing smart grid project results and benefits, with the scope encompassing: policy, standards and regulations; finance and business models; technology and system development; user and consumer engagement; and workforce skills and knowledge. As of this report date, 22 countries are involved in ISGAN from Asia, Australia, Europe, and North America.[38]

3.5. Evaluation & Demonstrations

The Evaluation and Demonstrations topic area focuses on assessments and experiments of state-of-the-art technology areas and incentive programs that are indispensable for achieving the full potential of the smart grid. Evaluation and demonstrations will be from the perspective of

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[37] Available at http://www.smartgrid.gov/sites/default/files/doc/files/sgig-progress-report-final-submitted-07-16-12.pdf.

[38] Information on ISGAN and its current Participants can be found at http://www.iea-isgan.org/.

distribution system interaction with the rest of the electric power system. The scope includes fundamental requirements of existing distribution systems and how these systems need to evolve in terms of new functions and requirements to facilitate smart grid concepts. For instance, evaluation and demonstrations will be used to determine how the existing system with mostly inactive devices in the distribution system should evolve to one in which the distribution system plays a much more active role in supplying local and reactive power to support and integrate with the transmission system. The scope of this topic area will also cover characterization of external interfaces with the transmission system, system pricing markets, EPS operators and local customers, and smart, demand-responsive loads. In the future smart grid, high-speed and time-synchronized data measurements will enable faster control for responding to transients and disturbances and providing information on the dynamic state of the system and how it corresponds to the transmission system. Thus, required technologies will involve those that directly control power and voltage, as well as those that measure system parameters and provide communication and control functions.

Evaluation and demonstration activities are closely coupled with other areas of the MYPP. Innovative components and systems will be evaluated in terms of emerging standards and best practices and future smart grid needs toward achieving interoperability between technologies. Test data gathered from the ARRA smart grid investment grants and demonstrations will be used in smart grid analysis to evaluate performance gains with smart technologies and areas for improvement and to calibrate and validate software models for new methods and technologies.

Evaluation and Demonstration will be focused on: 1) SGIG projects, 2) demonstration projects, 3) other DOE sponsored projects and components under R&D, 4) relevant projects and components “by others” (states, utilities, manufacturers, industry, etc.) and 5) ongoing projects by the national laboratories. Evaluation and demonstration activities should address important existing and new R&D issues and determine key application areas for future research and testing. Of particular importance is the need to identify gaps in existing technologies and processes that could limit successful, cost-effective roll-out of smart grid systems or gaps related to smart grid functionality. This section will identify a set of high-impact activities where federal R&D efforts can address barriers and technology gaps, and help bring about or accelerate significant technology advancements and implementation through evaluation and demonstration.

3.5.1. Technical Goals and Objectives

The technical goals and objectives are:

- Characterize the performance of smart grid systems and components throughout the distribution system: from the substation to the end-user loads.
- Verify and validate intended functionality, requirements, etc. under various modes of operation and in various scenarios. Identify performance gaps in terms of areas of improvement.
- Develop protocols and methods for testing and evaluating new components and systems.
- Develop and document capabilities for testing and evaluation.

- Develop generic methods and procedures for predicting the success of various projects based on demonstrable, definable, and repeatable metrics. This could be of value to projects that are in process and new projects for the future.
- Evaluate performance and compare to expectations and baselines; identify gaps.
- Develop and maintain a financial and technical performance results database accessible by utilities to provide proof points to assist with building business cases and encourage them to invest in the highest payback opportunities.

3.5.2. Technical Challenges

Because of the diverse and nascent nature of smart grid equipment and processes, it will be challenging to create standardized or effective tests in this domain. Many of the testing processes will evolve and set standards once they have achieved some level of maturity. Many projects associated with evaluation and demonstration described here are either in process or not started. Furthermore, gathering test data from ARRA SGIG and demonstration projects may be difficult unless explicitly defined in the scope of work and data design for those projects. Even then, some data later determined to be necessary may not be available. NERC CIPs may restrict some of the needed data. Therefore, synthetic data via simulation routines may be needed to fill the data gap. The challenge will be developing good methods and models to create such data, possibly through test systems.

3.5.3. Technical Scope

Evaluation and demonstrations will apply to:

- Microgrid architecture, control, and protection.
- Process and industry interaction to determine performance metrics.
- Methods to determine relevant testing and compliance criteria for a given project or demonstration.
- Methods to evaluate compliance with testing criteria.
- Methods to document results (per defined criteria).
- High-level evaluations of performance, relevant applications, etc. (expert analysis & insight beyond pre-defined criteria, e.g., system effects).

3.5.4. Status of Current Development

- There is ongoing expedited activity by NIST and other organizations to establish standards to “achieve interoperability of smart grid devices and systems…” [EISA Title XIII 1305].

- ARRA SGIG and SGDP projects are underway. The ARRA-funded Smart Grid Regional Demonstrations aim to verify smart grid technology viability, quantify costs and benefits, and validate new business models that can later be adapted and replicated around the country. The goal of these 16 SGDP projects is to provide the information necessary to enable customers, electricity distributors, and electricity generators to reduce electric power system demands and costs, increase energy efficiency, match electricity demand and resources, and increase the reliability of the grid.
- Other DOE sponsored projects and components.
- Relevant projects and components "by others" (states, utilities, regions, ISO, RTO, etc.).

3.5.5. Technical Task Descriptions

- Create documents and other deliverables that define processes to achieve outlined goals. Develop strategy and methods for disseminating findings to stakeholders of all types.
- Manage processes to achieve goals outlined above.
- Evaluate projects, processes, and components based on ability to meet the goals of improving smart grid system value streams discussed in the *Analysis* section.

3.5.6. Milestones

Milestones are listed in terms of near-, mid-, and long-term objectives:

Near Term (1-2 years)

- Develop project prioritization methodology.
- Evaluate current industry, laboratory, and government capabilities (testing).
- Identify performance gaps in terms of areas of needed improvement, and base ranking on priority and required funding.

Mid Term (3-4 years)

- Verify and validate intended functionality, requirements, etc. under various modes of operation and in various scenarios.
- Develop protocols and methods for testing and evaluating new components and systems.
- Develop and document capabilities for testing and evaluation.
- Develop generic methods and procedures for predicting the success of various projects based on demonstrable and repeatable metrics. This could be of value to projects that are in process and new projects for the future.
- Evaluate performance and compare to expectations, baselines; identify gaps.

Long Term (5+ years)

- Provide feedback to existing projects.
- Provide suggested areas of high impact future R&D.
- Evaluate benefits to the full vision of the smart grid.

3.5.7. FY 2012 Accomplishments

The DOE has joined with the Departments of Defense and Homeland Security in launching SPIDERS, which involves phased demonstrations of microgrids at three military bases (Pearl Harbor-Hickam Air Force Base, Hawaii; Fort Carson, Colorado; and Camp Smith, Hawaii), with each having progressively larger and more complex scope than the previous. Five national laboratories (SNL, NREL, ORNL, Idaho National Laboratory [INL], and PNNL) are participating in SPIDERS. The project extends previous Energy Surety Microgrid conceptual design work supported by the Smart Grid R&D Program and proceeds to the detailed design, installation, demonstration, and operation phases. The project will complete with transitioning standardized procedures on design approach, contracting, security, and operation of these microgrids to support future applications. During the period from FY 2011 to FY 2014, SPIDERS will demonstrate:

- Cyber-security of electric grid
- Smart Grid technologies & applications
- Secure microgrid generation & distribution
- Integration of distributed & intermittent renewable sources
- Demand-side management
- Redundant back-up power systems

The DOE led establishment of ISGAN Annex 5: Smart Grid International Research Facility Network (SIRFN) in 2012. Under SIRFN, existing research and test facilities internationally will be leveraged for use by participants to evaluate smart grid concepts and technologies targeting the niche areas between R&D and commercialization. Testing and evaluation capabilities are being established for the following areas:

- Renewable energy/distributed energy integration
- Building automation
- Electric vehicles integration
- Microgrids
- Distribution automation
- Cyber security

4. Program Management

4.1. Program Portfolio Management Process

Principal areas of program management integral to the Smart Grid R&D Program include:

- Portfolio development and management
- Communication of the program
- Analysis of the program
- Evaluation of the program
- Technology transfer

These management areas combine to ensure that industry, the public, and government are effectively served by the Smart Grid R&D Program. This program follows a multi-step planning and management process designed to ensure that all funded technical R&D projects are chosen based on qualifications in meeting clearly defined criteria. This process entails the following:

- Competitive solicitations for financial assistance awards and national lab research, development, demonstration, and deployment (RDD&D).
- Peer reviews of proposals in meeting the FOA goals, objectives, and performance requirements.
- Peer reviews of in-progress projects on the scientific merit, the likelihood of technical and market success, the actual or anticipated results, and the cost effectiveness of research management. The Smart Grid R&D Program and its in-progress R&D projects will be reviewed through this external review process once every two years, with evaluation results feeding back to program planning and portfolio management. The 2012 Smart Grid Peer Review occurred on June 7-8, 2012, in San Diego, CA.[39]
- Stage gate reviews to determine readiness of a technology or activity to advance to its next phase of development, pursue alternative paths, or be terminated; these readiness reviews will be conducted on an as-needed schedule based on project progression in meeting the established stage gate criteria.
- OE internal review of the Smart Grid R&D Program annually to ensure continuous improvements and proper alignment with R&D priorities and industry needs.

The value of R&D projects, individually and collectively, to achieving the Smart Grid R&D program goals will be made transparent by applying this management process consistently throughout the Program. Moreover, this value that is supported by rigorous analysis and evaluation will be transparent in Program communications to the industry, the public, and other smart grid stakeholder organizations.

This MYPP will be used to guide ongoing projects and development of the Smart Grid R&D Program portfolio of projects through 2014, and will be updated annually to reflect current state of advances, priority needs, and resources availability. Implementation schedules for the Tasks described in the MYPP will depend on annual appropriations of the Program budget.

4.2. Performance Assessment

The OE defines the smart grid by seven performance-based functionalities; these functionalities will lead to achieving the Smart Grid R&D Program’s 2020 goals:

- Commercially viable microgrids
- A self-healing electric distribution grid
- High penetration of DER, DR, and PEVs in distribution grid

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[39] Information on the 2012 Smart Grid Peer Review is available at: http://energy.gov/oe/articles/smart-grid-rd-program-peer-review-june-7-8-2012.

Annual milestones toward achieving the Program outcomes are listed in the table below:

	2012	2013	2014
High Penetration of RE, DR, and PEV in Distribution Grid	Demonstrate integration of renewable and distributed systems for a 12% load factor reduction on a distribution feeder circuit		
Commercially Viable Microgrids		Demonstrate a smart microgrid at a portion of the Joint Base Pearl Harbor-Hickam with no mission-impacting power interruption	Demonstrate an operational prototype of a smart microgrid including integration of electric vehicles and renewable energy
Self-healing Distribution Grid			
	2015	**2016**	**2017**
High Penetration of RE, DR, and PEV in Distribution Grid			
Commercially Viable Microgrids			Complete a commercial microgrid system capable of reducing outage time of critical loads by >98% at twice the cost of a backup system
Self-healing Distribution Grid	Demonstrate an energy management platform that integrates legacy systems with smart grid assets and models for self-healing switching functionalities at a utility substation	Test advanced algorithms for fault location, isolation, and a self-healing distribution network in a utility's real operating environment to support automated switching and reconfiguration operations	

The Smart Grid R&D Program will apply consistent methodology to quantify smart grid benefits annually in terms of peak demand reduction, system efficiency, grid reliability and resilience, renewable and distributed energy resources, and penetration of PEVs in support of the Smart Grid 2020 goals.

Appendix 1: Acronyms

Acronyms	Meaning
AEP	American Electric Power
AM/FM	automated mapping/facilities management
AMI	advanced metering infrastructure
ANL	Argonne National Laboratory
ARRA	American Recovery and Reinvestment Act of 2009
BEM	building energy management
CERTS	Consortium for Electric Reliability Technology Solutions
CIM	Common Information Model
CPP	critical peak pricing
CVR	conservation voltage reduction
DER	distributed energy resources
DG	distributed generation
DMS	distribution management system
DoD	Department of Defense
DOE	Department of Energy
DR	demand response - the adjustment of end-user loads based on communications between the end-user and the service provider or markets
E2RG	Energy and Environmental Resources Group, LLC
EE	energy efficiency
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EISA	Energy Independence and Security Act of 2007
EMCAS	Electricity Market Complex Adaptive System
EMS	energy management systems
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EPS	electric power system
EV	electric vehicle
EVSE	electric vehicle supply equipment
FCC	Federal Communications Commission

Acronyms	Meaning
FERC	Federal Energy Regulatory Commission
FOA	Funding Opportunity Announcement
GIS	geographic information systems
GW	gigawatt
GWAC	GridWise Architecture Council
HVAC	heating/ventilating/air conditioning
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IIT	Illinois Institute of Technology
INL	Idaho National Laboratory
ISGAN	International Smart Grid Action Network
ISO	independent system operator
kW	kilowatt
LBNL	Lawrence Berkeley National Laboratory
LSE	load serving entity
M&V	measurement and verification
MISO	Midwest Independent System Operator
MW	megawatt
MYPP	multi-year program plan
NERC	North American Electric Reliability Corporation
NETL	National Energy Technology Laboratory
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
OE	Office of Electricity Delivery and Energy Reliability
ORNL	Oak Ridge National Laboratory
PEV	plug-in electric vehicle (includes plug-in hybrids and all electric vehicles)
PHM	prognostic health management
PMU	phasor measurement unit
PNNL	Pacific Northwest National Laboratory
PQR	power quality and reliability
PSERC	Power Systems Engineering Research Center

Acronyms	Meaning
PV	photovoltaic (solar power)
R&D	research and development
RD&D	research, development, and demonstration
RDD&D	research, development, demonstration, and deployment
RDSI	Renewable and Distributed Systems Integration
RT	real time
RTDS	Real-time Data Simulator
RTO	Regional Transmission Organization
SAIDI	System Average Interruption Duration Index
SCADA	supervisory control and data acquisition
SDG&E	San Diego Gas & Electric
SGDP	Smart Grid Demonstration Program
SGIG	Smart Grid Investment Grant
SIRFN	Smart Grid International Research Facility Network
SNL	Sandia National Laboratories
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability and Security
SVC	static VAR compensator
T&D	transmission and distribution
ToU	time of use
V&V	verification and validation
VAR	volt-ampere reactive (reactive power)