Action Plan Addressing the Electricity Distribution System

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Table of Contents

INTRODUCTION

Access to reliable, cost-effective electricity has been a key driver of economic development and is critical to sustaining modern society. Current trends towards cleaner energy and increased consumer participation in conjunction with aging infrastructure are greatly stressing the U.S. electric power system. For example, the rapid adoption of rooftop photovoltaic (PV) systems and plug-in electric vehicles (PEVs) will substantially impact distribution grid operations. At the same time, numerous grid assets are near or past their end-of-life and present opportunities for replacement with more advanced technologies.

The complex and pervasive nature of the electric power system means that no single entity will be able to overcome the numerous challenges associated with grid modernization. Based on this understanding, the Department of Energy (DOE) proposes a strategy centered on engagements with stakeholder communities; this paper and its associated workshop are important steps in that process. The purpose is to identify priorities, national goals, and specific targets necessary to advance technologies needed to modernize the grid and meet these challenges.

Due to the scale of this overall effort, this paper and its associated workshop will, together with other inputs, inform the development of a technical roadmap focused on modernizing the electricity distribution system. The workshop will also help identify the DOE's role in addressing key challenges in this space. The DOE is seeking input from a broad range of electricity sector experts that will shape the development and execution of a five-year research plan. This document in its current form serves as a preparatory guide for the Distribution Workshop and will contribute to the subsequent development of a detailed technology R&D roadmap.

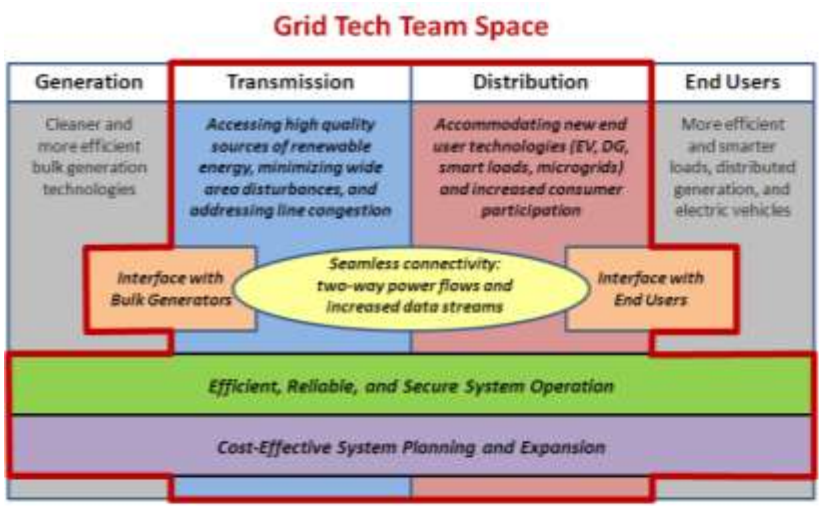

Figure 1 – Systems Perspective of Grid Challenges and the GTT

The Grid Tech Team

The DOE recognizes the enormous complexity of modernizing the electric grid, especially with the many challenges associated with integrating technologies, policies, and systems together in the face of rapid technological and institutional changes. There are tremendous opportunities to improve the physical dimensions of the grid, which include generation, transmission, distribution, and end users. Additionally, there are opportunities to enhance the system dimensions of the grid, namely its interfaces, connectivity, operations, and planning. There is also a myriad of challenges posed by uncertainties in technical, regulatory, policy, and market conditions at the local, state, and federal levels. With the understanding that a holistic systems perspective is needed to address these complexities, the Grid Tech Team (GTT) was established to coordinate and synchronize all grid-related activities across the DOE.

The DOE has many offices and programs that specialize in research and development, spanning generation through end-use technologies. These offices include (but are not limited to) Fossil Energy

(FE), Electricity Delivery and Energy Reliability (OE), The Office of Science (SC), ARPA-E, and Energy Efficiency and Renewable Energy (EERE). While these offices have long been working on research projects associated with various aspects of the grid, much of the work has been focused within their respective realms.

The GTT was established to take a holistic systems approach across these efforts to coordinate activities and develop recommendations for future R&D. As shown in Figure 1, the GTT is primarily concerned with transmission, distribution, and the systems aspects of the grid. Generation and end-use technologies are outside the purview of the GTT. Nevertheless, the interfaces and connectivity of those technologies with the transmission and distribution system requires careful consideration to ensure cost-effective system planning and expansion as well as the efficient, reliable, and secure operation of the grid.

Focus on Distribution

A modernized grid must be able to accommodate the challenges associated with integrating variable energy resources (rooftop PV), smart grid technologies, plug-in electric vehicles (PEV), energy storage systems, and transactive residential, commercial, and industrial building loads, to name a few key technologies. An enhanced distribution system will be a critical enabler for the increased deployment of these clean energy resources and energy efficient systems. The technical and institutional challenges of grid integration are amplified by the need to simultaneously deploy existing technologies while establishing conditions that can incorporate emerging technologies into a cohesive distribution system.

DOE has made substantial investments in technologies leading to innovations in modernizing the distribution system. Many of these innovations, however, have targeted the discrete technologies that are being integrated into the system without a broad perspective of the whole system. As a result, more consideration is needed with a systems perspective across the different technologies in order to address the numerous opportunities and challenges of integrating them into the grid. A coherent, holistically designed, and efficient distribution system that can seamlessly connect with the transmission network is needed to increase deployment of clean energy technologies and unlock efficiency potentials at the end-user level.

Roadmap Goals

The DOE intends to work closely with various stakeholder communities to establish a clear and comprehensive vision for a 21st century distribution system and a corresponding DOE research and development roadmap. The GTT would like to identify opportunities and challenges for the integration of current and future technologies into the distribution system and associated R&D needs. This is a critical step in the development of a DOE R&D roadmap that can help overcome these challenges and realize the opportunities of a modern distribution system. The roadmap will identify barriers to the development of a fully integrated distribution system, set goals, and lay out plans for the next five years to help realize the vision.

PROCESS OVERVIEW

The purpose of this section is to provide a baseline context for participants in the Distribution Workshop and for any other parties interested in contributing to the DOE's road mapping process. By acknowledging efforts already underway, describing current conditions, and identifying critical opportunities and challenges, participants in the workshop will propose a series of solutions that DOE can consider in developing its research roadmap. Ultimately, the roadmap will help inform funding opportunities in support of an R&D agenda that aims to achieve established objectives.

The development of a detailed research roadmap includes the following steps:

For the DOE:

1) Draft DOE's action plan for grid integration at the distribution level and its linkages with bulk transmission; this is the document in hand. This document establishes a baseline context of the status of ongoing efforts in distribution grid integration, identifies key opportunities and challenges in distribution grid integration, and proposes specific questions for discussion during the workshop.

2) Convene a workshop(s) of electricity sector experts to identify, verify, and prioritize key challenges.

3) Based on the results from the workshop(s) and other inputs, develop a draft roadmap for grid integration at the distribution level, post a Request For Information (RFI) to gather public input on this draft roadmap, and finalize the results including action items and expected outcomes.

For Workshop Attendees:

1) Review this paper and provide written comments.

2) Participate in the workshop: identify key opportunities and challenges for holistic grid integration, validate or question those identified in this document; refine the associated technology R&D needs and priorities in the near-, mid-, and long-terms; and verify desirable overall programmatic R&D goals.

3) Provide additional feedback on the DOE's draft research roadmap when it becomes available for public comment.

DISTRIBUTION SECTOR SKETCHES

There are numerous technological advances that are impacting the distribution system. Their interactions pose many challenges as well as opportunities for synergies. An overview of these various technology areas are presented below to help frame discussions at the Distribution Workshop.

Distributed Generation: Variable

Overview

Many states have adopted renewable portfolio standards and incentives out of growing concerns about environmental issues and to diversify their generation portfolios. Together with rapid and continuing technology cost reductions, variable energy resources (VER) such as photovoltaics (PV) and wind are thus expected to become a larger part of our energy portfolio during the next several decades. As these technologies mature, they have the potential to supply a significant share of our nation's electricity demand. As their market share grows, concerns about their potential impacts on the operation of the distribution system are likely to increasingly emerge. This is due to their variable, non-dispatchable nature and because the distribution system was not originally planned for multi-directional power flow.

As the deployment of VERs on electric distribution systems have accelerated in recent years, utilities, regulatory agencies, and developers have been faced with a significant number of integration challenges. Higher levels of PV penetration and larger PV plant sizes are forcing many interconnection requests into supplemental studies that often create delays and increase costs. However, case studies of high-penetration distribution feeders in the United States and Europe clearly indicate that there are effective methods for integrating PV systems at higher penetration levels, and the DOE is currently supporting further development of solutions that will reduce delays and costs. This includes developing inverters with advanced functionalities through the Solar Energy Grid Integration Systems (SEGIS) program,[1] testing and demonstration through the High Penetration Solar Deployment program, and the development of new system architectures through the Plug and Play initiative.

Key Opportunities & Challenges

- Technical Challenges: Utilities are concerned about the technical challenges of distributed variable generation resources, including (a) voltage regulation; (b) islanding; (c) protection coordination; (d) reverse power flow; and (e) power compensation when variable renewable resources are unavailable.
- Impact Studies: Many utilities may require impact studies to determine if VERs interconnected to the grid will cause problems and potentially require system upgrades. These impact studies often require data on the distribution system that is not readily available. They also require static and dynamic PV system models that are only in the early stages of development.
- Distribution Management Systems: Due to the proliferation of new technologies that are ready for installation on the distribution system, managing its operation is becoming much more difficult. Distribution management systems (DMS) will need better visibility of system components in order to communicate with and coordinate the operation of a variety of technologies in a holistic manner.

[1] A number of studies have been completed at https://solarhighpen.energy.gov/segis_completed and others underway and related information can be found at http://www1.eere.energy.gov/solar/rsi.html and https://solarhighpen.energy.gov/

Questions for Consideration

- What are cost-effective, reliable ways to address technical integration issues such as voltage regulation, islanding, protection coordination, and reverse power flow?
- How can interconnection impact studies be performed faster without compromising the reliability of the system?
- How can VERs operate holistically with the host of other technologies being developed for the distribution system including electric vehicles, demand response, and other DG? What communications and control systems are needed between the end-user and the utility—from the distribution system to the grid operator—to enable effective integration of these distribution-level systems with the overall grid?
- What codes and standards need to be developed or updated to allow for the future distribution system to operate with higher penetrations of VER?
- What information and communications is needed with regard to cyber security?
- What finance, market, and policy/regulation challenges does high penetration of VER pose for utilities, including net metering and low locational marginal pricing?
- What costs and benefits does VER raise with respect to grid ancillary services? How can these best be determined and addressed?
- Which of these challenges are specific to the technology and which require more holistic considerations, as described below in the Systems Perspective section?

Distributed Generation: Dispatchable

Overview

Distributed generation that is dispatchable can be used in lieu of or as a supplement to central station power plants to provide grid services, such as:

- Capacity and Energy
- Operating and Spinning Reserves
- Regulation and Frequency Response
- Reactive Power and Voltage Control

By responding to dispatch signals from system operators, these resources can generate or reduce power to complement the variable output of solar and wind power and to help meet peak demand. The electric power system requires constant balancing or regulation of generator power flows and customer loads that constantly fluctuate. Grid systems use regulation response services to adjust output in relation to demand. Ancillary services keep the system within electrical and safety tolerances. These services adjust generator output to:

- balance momentary fluctuations in generation and load;
- maintain synchronized reserves (which is unloaded generation that is synchronized with the grid and ready to serve additional demand that can quickly be removed from the system); and
- provide voltage support, reactive power, and frequency regulation.

Dispatchable DG includes conventional combustion engines and turbine generators, microturbines, and fuel cell systems. Engines and turbines are known for their ability to provide operational flexibility due to their short ramp times to partial or full load.[2] Fuel cell systems provide exceptionally clean power while operating quietly with very low emissions and at high efficiency at all scales. A hybridized fuel cell with a peaking polymer-electrolyte-membrane stack adds dynamic performance and leverages automotive fuel cell component volumes. Both fuel cells and microturbines provide electrical output through inverters that can condition power and precisely match grid requirements. Microgrids that incorporate distributed generation are also technically capable of providing ancillary services.

All of these systems can be designed to provide combined heat and power (CHP). Their capabilities vary, but can be characterized by key parameters that matter to the grid, such as capacity and response time. With standardized signal specifications, grid communication protocols, and corresponding electronic controllers and power electronics, the potential exists for distributed generation products to be operated in automated real-time marketing and control modes.

Key Opportunities & Challenges

Though, rules for procurement and financial settlement are fairly complex, conventional DG can participate in capacity and energy markets. Provision of these services is tied to the design of the energy market and the location of the resources relative to the locational needs of the grid. Procurement of these commodities can be through regulated systems or market-based systems.

In areas of the U.S. with organized wholesale markets, a conventional DG facility can sell ancillary services, depending on its operational characteristics and the requirements of the particular market. However, participation is currently very low across the U.S., partly because each of the markets for these services is highly specialized with complicated rules. Participation requirements include metering that allows for financial settlement, active market engagement, and periodic education to maintain certification. These requirements are not in DG project operating budgets and may be considered as not aligned with commodity production.

ISO/RTOs also specify minimum participation sizes for connection to the grid. These sizes range from 100kW to 1MW. As a result, ancillary services often require third party aggregators or the load serving entity, to arrange on behalf of the DG owner. Third party aggregators are not allowed in all states and most load serving entities must file a retail tariff with a state utility commission, which has not been done successfully to date.

Customer-sited DG/CHP tends to be run for the primary use of the customer to meet its electric and thermal loads. As such, it is difficult for this form of DG to currently participate in the ancillary markets due to complexity of the rules, and the grid operator's dispatch requirements which can run counter to needed services for the site. However, participation in ancillary service markets could be accomplished if the system were configured appropriately (e.g., whereby single or multiple prime movers have excess capacity and can still meet all thermal needs, or during times when the thermal load is predictably low, affording excess electrical generation to be available).

Dispatchable DG and third party provision of ancillary services have moved from study papers to existing programs of the ISO-NE, NYISO, MISO and the SPP. Furthermore, integrating DG, DR, and storage technologies continue to be a regulatory focus of FERC to further facilitate the provision of

[2] Gas engines can reach full load in several minutes, gas turbines in less than ten minutes.

ancillary services from all resource types in competitive markets.[3] As previously discussed, there are challenges to dispatchable DG. State commissions working with FERC can play a major role in advancing the use of dispatchable DG at the distribution level.

Questions for Consideration

- What is needed—technically, operationally, and institutionally—to allow customer-sited dispatchable DG to participate in the ancillary services market of all ISO/RTOs?
    - What are the distribution system design, safety, operational objectives, and standards that must be met?
- Can the rules of participation for dispatchable DG be standardized across ISO/RTOs?
- What capabilities are needed from the DG prime mover technologies in order to provide ancillary services?
- What is the role of dispatchable DG in grid-connected, microgrid, and island mode applications?
- What are the operating requirements for grid connected vs. island mode applications?
- What smart grid technologies can facilitate dispatchable technologies?
- What policies/initiatives for dispatchable DG and variable distributed generation are needed to facilitate grid integration of these resources?
- Which entities should be responsible for adopting/setting/enforcing these regulations?
- Which of these challenges are specific to the technology and which require more holistic considerations, as described in the Systems Perspective section of this document?

Smart Grid Technologies

Overview

Smart grid technologies on the distribution system deal with two-way communication and information exchanges with distributed energy resources (DER), smart architectural control of those resources (centralized vs. distributed vs. combinations of the two), and the interactions between various technologies including those within consumer premises. Communication, control, and information systems that encompass smart grid technologies provide sensing, neural, and intelligent response functions for other technologies. These include dispatchable and non-dispatchable DG, energy storage, EV charging, and demand-responsive building loads. Additionally, these technologies have the potential to enable the communication, control, and optimization of DER and loads for operation as a microgrid or a collection of microgrids, in both grid-connected and islanded modes.

Through the Recovery Act Smart Grid investments, over 5% of the nation's distribution circuits will be equipped with upgraded communication, control, and information technologies to provide better management of outages, voltage levels, and reactive power. An additional 10% of the population will be served by smart meters, contributing toward the 65 million smart meters that industry estimates will be installed by 2015.

[3] NOPR, Docket Nos. RM11-24-000 and AD10-13-000, June 22, 2012

Much work remains to be done, however, to integrate these technologies into smart grid architectures. Some integration activities are being supported by the 2009 Recovery Act (ARRA) Smart Grid Demonstration Program and the OE Smart Grid R&D Program. These formal projects intend to demonstrate the operation of distributed assets (DER, DR, and EV) with smart grid architectures to validate business cases. The OE Smart Grid R&D program includes the Renewable and Distributed Systems Integration (RDSI) projects, which are making progress towards the goal of at least 15% peak demand reduction.

The Smart Grid R&D Program also supports the design, analysis, and demonstration of microgrids involving smart grid technologies and distributed assets. Fast-responding voltage regulators and dynamic VAR compensators under high penetration of VER and smart inverter controls for microgrids are being developed in laboratory prototypes. Current activities show that existing technologies will not sufficiently enable cost-effective solutions that can seamlessly integrate distributed assets with smart grid technologies and architectures.

Key Opportunities & Challenges

- New smart grid architectures and operational concepts that must be developed to integrate distributed assets for protection coordination, operational control, and automation.
- New smart grid interoperability framework and standards to allow plug-and-play coordinated operations of all devices and systems connected to the grid, including coordination with legacy systems.
- New cyber security guidelines and standards governing all newly introduced digital interfaces, devices, and systems, and the resulting digital infrastructure.
- New tools for utilities, regulators, and consumers to make smart grid business decisions.

Questions for Consideration

- What is the proper balance of smart grid technologies and assets within new smart grid control architectures? What are the criteria for “right-sizing”?
- What is the value proposition for greater penetration of smart grid technologies for end users, electricity service providers, and distribution and transmission providers?
- Do we need to develop new protection, coordination, and control methods for high penetration levels of inverter-based DERs; what should they be?
- What are tools that can be employed to model and design for added uncertainty from smart grid technologies? What are methodologies that can be used to stress test designs?
- Are the available communication protocols sufficient for variable renewable resources, and, if not, what additional protocols are required?
- How do we ensure that interconnections of smart grid technologies are cyber secure?
- To what extent can energy storage and EV be used for ancillary services?
- What communications and controls are required for each DER, coordination among DERs, and between DER and the distribution utility?
- What is the mechanism for recovery of smart grid investments that produce efficiency gains and thereby reduce utility revenues in both regulated and unregulated markets?
- Which of these challenges are specific to the technology and which require more holistic considerations, as described in the Systems Perspective section of this document?

Plug-in Electric Vehicles (PEVs) and Fuel Cell Electric Vehicles (FCEVs)

Overview

Automobile manufacturers continue to introduce new plug-in electric vehicles (PEVs) and have announced plans to introduce fuel cell electric vehicles (FCEVs) into the marketplace. Consumer adoption of these vehicles will increase as manufacturers make them available. Electric vehicle supply equipment (EVSE, commonly referred to as "charging station"), and electrolysis-based hydrogen production will represent large, controllable, distributed electrical loads that must be managed in order to prevent adverse impacts to the grid while providing convenience and value to the consumer.

Opportunities also exist to exploit synergies between PEV charging, electrolyzers, renewable generation, building energy management systems, DC micro-grids, stationary grid storage systems, and smart grid technologies. These synergies can leverage the controllable loads of electrolyzers and ultimately transform PEVs into an asset for the grid. Electrolyzer-based hydrogen production systems incorporate energy storage (hydrogen tanks), and thus are not constrained to producing hydrogen and refueling vehicles simultaneously. This allows loads to be spread over a larger period of time or scheduled during off-peak hours and when renewable energy is produced. The hydrogen is stored on-site and quickly dispensed on-demand.

In 2011 – the first full year of wide-scale availability for plug-in vehicles – approximately 17,700 PEVs were sold in the U.S. American consumers purchased an additional 21,000 PEVs in the first seven months of 2012.[4] While these numbers are not insignificant, they represent only a small fraction of the 241-million light-duty vehicles currently registered in the United States.[5] These vehicles recharge at 4,287 publicly available charging stations[6], and countless private and workplace EVSEs,[7] at rates from 1.2kW for AC Level 1, to 3.3kW-6.6kW for AC Level 2, to 50kW for DC Fast Charging.

Several hundred fuel cell electric vehicles (FCEV) have been deployed in the U.S. in recent years. Most major automobile manufacturers with fuel cell programs are targeting commercial launch of these vehicles for 2015-2017. Combined OEM sales volumes are expected to be in the range of 30,000 to 50,000 during this period. Hydrogen stations in the 2015-2017 timeframe are expected to have an average size of 400-500 kg/day. Ultimate station sizes could be in the range of 800-1500 kg H_2/day as the FCEV market matures[8]. Electrolysis stations in the 400-500 kg/day range should have electrical power needs of 900-1,100 kW, while 800-1,500 kg/day stations should need approximately 1.8-2.4 MW.[9]

[4] http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952, accessed August 16, 2012.
[5] http://cta.ornl.gov/data/chapter3.shtml, Table 3.4, accessed August 16, 2012.
[6] http://www.afdc.energy.gov/fuels/electricity_locations.html, accessed August 16, 2012.
[7] No total count is maintained for private/non-publicly accessible charging stations. However, over 7,000 residential EVSEs have been deployed through DOE-funded programs as of July 31, 2012.
8 California Fuel Cell Partnership, "A California Road Map: The Commercialization of Hydrogen Fuel Cell Vehicles." June 2012.
[9] Electrolysis power only, based on H2A "Current Forecourt Hydrogen Production from Grid Electrolysis 1500 kg per day version 3.0". http://www.hydrogen.energy.gov/h2a_prod_studies.html. Accessed August 20th, 2012.

Key Opportunities & Challenges

- Behavior Modeling: As market adoption of PEVs continues, it is important to understand how consumers use these vehicles, and in turn how their utilization of charging infrastructure impacts the electric grid.
- Clustering of EVs: It is likely that "clustering" of PEVs being charged overnight at owners' residences in particular areas may result in localized distribution transformer overload, compromising transformer service life.
- Managing Production Loads: Higher market penetration of PEVs and electrolysis-based hydrogen stations results in questions regarding how to manage the charging and hydrogen production loads so that they do not coincide with peak demand from other sectors, which would result in additional needed generation capacity.
- Enabling Variable Distributed Generation: Ultimately, a mature market for PEVs and FCEVs could be an enabler for variable distributed generation such as wind and solar photovoltaic (PV) systems. For example, wind generation reaches its peak during the night, but in some regions must be curtailed due to low demand; wind could then be used to recharge PEVs or fuel FCEVs.
- Controlling PEV charging and hydrogen production so that they coincide with nighttime wind generation could provide value to consumers, through favorable electricity rates, and to utilities, by providing demand for this generation.

Questions for Consideration

Questions remain regarding the degree to which PEVs and FCEVs will penetrate the automotive market, and to what extent these vehicles will represent challenges and opportunities to the grid; its transmission and distribution systems; the generation sources that supply it, and other demands that must be met. Addressing these issues requires cross-cutting analysis, with engagement from electric utilities, regulatory agencies, PEV charging infrastructure providers, hydrogen infrastructure providers, automobile manufacturers, energy service providers, and other stakeholders.

Important topics/questions include:

- At what level of market penetration, and at what charging rates, do PEVs become a concern? What mitigation strategies are required to prevent adverse impacts to the grid's distribution system as PEVs are introduced?
- Are there limitations of the electrical grid that will impede deployment of electrolysis-based hydrogen fueling infrastructure? At what level of market penetration does it become a concern?
- What are the most cost-effective models for integrating PEV charging and electrolysis-based hydrogen fueling with distributed renewables?
    - What other technologies are required? (Smart grid? Energy storage?)
    - What additional services can be provided? (Demand response? Frequency regulation?)
- What links exist between PEVs, FCEVs, and natural gas vehicles? Are there opportunities for synergy?

- What technical, market, and regulatory barriers exist that hinder the efficient integration of PEV charging infrastructure and electrolysis-based hydrogen infrastructure with the grid? How can these barriers be addressed?
- How can PEV and FCEV costs and benefits on the distribution grid best be identified and appropriately allocated between the end-user and the utility?
- Which of these challenges are specific to the technology and which require more holistic considerations, as described in the Systems Perspective section of this document?

Residential, Commercial, and Industrial Building Loads

Overview

Residential, commercial, and industrial building loads account for more than 70% of the electric load in the U.S. Within buildings, systems and components can provide user, energy, financial, and electric grid benefits through improved management of electricity consumption. In addition, there are potential synergies with other energy-related products and services including electric vehicles and renewable energy resources.

At the current state-of-the-art for these facilities, energy related systems and components are controlled in linear or small closed-loop methodologies that deliver non-optimal operation. Generally, they are unaware of external or global perturbations and opportunities; and control and dispatch of loads and on-site generation is typically rudimentary with heavy user interaction. For example, buildings are limited by existing controls systems that do not integrate functions performed by building management systems (BMS) and building energy management systems (BEMS) because of numerous constraints. There is a high cost to "get it right" with existing technology—currently only feasible in large buildings. Existing solutions are often customized, with high site-specific engineering costs, and thereby, are not-scalable. Emerging technologies with greater capabilities are not interoperable.

Therefore, there is currently limited ability or market to share performance information or transact load/energy services with other surrounding facilities or surrounding loads. In the near term, buildings could play a significant role in optimizing electric grid interactions and supporting grid integration of variable renewable electricity and plug-in electric vehicles, while still optimizing cost and operating parameters like occupant comfort, as defined (not continuously operated or controlled) by the owner/manager.

As an example of one of DOE's ongoing projects to help industry solve these problems, DOE's Building Technologies Program (BTP) is addressing various technical issues through its Sensors and Controls' sub-program. The goal is to optimize building performance and systems integration at the device level (i.e. component level) utilizing BEMS to enable buildings to transact for different attributes (i.e. comfort, price, performance, etc.).

BTP's strategy leverages existing capabilities in BEMS to monitor a building's needs and the condition of devices. This will allow BEMS to fully optimize the building's mechanical and electrical systems through enhanced control technologies and algorithms. These will, in turn, provide infrastructure for "smarter" components and analytics to make decisions. In addition, BTP is scoping the control needs for small/medium-size commercial buildings to enable them to be more energy efficient and also make these buildings more demand responsive. BTP is also developing solicitations to advance the state of building sensors, such that every significant building device or group of devices (whether generating or using electricity) is aware of how it is performing and how it could perform; and be capable of communicating those parameters to the BEMS to optimize energy management at the building and for the power system.

Key Opportunities & Challenges

DOE supports the vision of a comprehensive financial and physical system that allows significant participation by end users, products/service providers, and utilities to create and scale a sustainable and efficient electricity market -- success from this vision will provide behind-the-meter solutions to enable transactions for commoditizing energy related services. Currently, it is estimated that over 90% of buildings lack proper infrastructure to participate in this vision.

However, the existing state-of-the-art control systems are:

- Unable to communicate in a standard way and at an application-appropriate speed
- Incompatible with state-of-the-art security protocols
- Slowly and coarsely assembled into a 'system'
- Expensive to deploy, maintain, and commission/optimize
- Unable to "know" actual and potential operational characteristics
- Unable to communicate "gaps" between actual and potential

Even if the sensors and controls technology were cost effective and easy to install, hardware and software solutions must be developed with the capabilities to protect the owner/operator from negative consequences in order to address several market-based challenges.

Much of current effort still relies on rudimentary technology or extensive customization at each installation, which is neither cost-effective nor scalable. Furthermore, when the demand response strategies are deployed, the demand relief is unknown a priori. Therefore, the building owner does not have a clear picture of what the demand relief will be until after the event had passed.

The current approach works for certain types of demand response programs. However, it becomes more difficult if the building wants to bid into the capacity market, ancillary services market, or use price-based controls in real-time price markets. For these reasons, the huge potential for using the building load as a resource to mitigate supply and demand imbalance and to mitigate variation in generation from distributed renewable energy systems is not fully tapped. Unless fully-automated advanced algorithms are developed and deployed, widespread integration of buildings with smart grid is unlikely.

Questions for Consideration

- Buildings have the ability to change their 'presence' on the grid through the use of storage, load management, and distributed generation. What would be the requirements of these types of strategies for effective grid interactions (speed, scale, quality, reliability)?
- What is the baseline level of control activities that are wide spread in the market and what are their limitations at achieving effective grid interactions? What challenges do they face technologically and with respect to integrating at scale within buildings and utilities?
- Are there any building sub-systems that are likely to be useful to the grid if they could transact directly through the buildings electricity portal (utility meter)?

- What is the most grid friendly communications protocol that is likely to be supported by the largest number of grid management entities?
- What are the metrics or characteristics that buildings should define/provide to allow 'market' entities to rate the potential value of the building with respect to existing or new market based financial opportunities? What other key challenges exist to achieving this goal technically and deployed at scale within the market?
- Are there power system stability issues if responsive buildings are large providers of reliability services?
- What are cost-effective ways to aggregate responsive loads to take advantage of diversity and shape the load response to meet performance criteria that the underlying loads could not meet individually?
- How do you integrate responsive loads with control room operations and share resources for transmission-level support and distribution-level support?
- How do we incorporate price responsive demand into load forecasting algorithms to optimize system planning and the commitment and dispatch of grid resources?
- What is required in market transparency for developing functional demand response programs?
- Which of these challenges are specific to the technology and which require more holistic considerations, as described in the Systems Perspective section of this document?

Distributed Energy Storage (Electrical and Thermal)

Overview

Energy storage devices provide unique capabilities to the electric power system but also face unique challenges to deployment on the grid. Fundamentally, the power system must balance generation and consumption at every moment in time or the system will become unstable. Other than existing pumped storage hydropower facilities on the bulk transmission system, there has not been the ability to cost-effectively store energy and electricity. Understanding of these resources and how they can be used to optimize the operation of the electric power system requires more thorough investigation.

Energy storage provides a buffer through the shifting of energy – storing energy produced at one moment in time to be used at a later point. Depending on the characteristics of the storage device, the shifting can occur along multiple timescales based primarily on its capacity and energy ratings. This buffer adds to system flexibility, which becomes increasingly important with higher levels of variable renewables. Variable renewables, such as wind, solar, and tidal, introduce more variability and uncertainty into the power system.

Energy storage includes electrical energy storage and thermal energy storage. Thermal energy storage is similar to a demand response resource and can withdraw and inject electricity indirectly by changing the timing of its consumption. Electrical energy storage can have more value streams due to its ability to withdraw and inject power directly with the grid and is not subject to constraints imposed by the consumer of the thermal energy. There is also an opportunity for the secondary use of electric vehicle batteries once they have reached their primary application end of life.

Distributed energy storage has the potential to help defer system upgrades, reduce line losses, provide voltage support, improve power quality, help integrate distributed photovoltaic generation, support microgrids, and enable other functions.

Distributed thermal energy storage in the form of ice storage and hot water tanks has been commercial for some time and is considered mature. Electrical energy storage, mainly electrochemical batteries, is at various stages of maturity depending on the technology and chemistry. Sodium-sulfur (NaS), lead-acid, and nickel-cadmium (NiCd) battery systems have been deployed at substations in the past, while advanced lead-acid (lead-carbon), lithium-ion, and flow batteries have been deployed more recently at the distribution level and at substations through the Recovery Act. Advances in new chemistries, new system designs, and lessons learned from these demonstration projects will support integration of distributed energy storage devices into the grid.

Key Opportunities & Challenges

- Limitations in the cost and lifetime of electrical energy storage systems make it difficult to justify the investment.
- Aggregation of distributed energy storage devices is not well understood.
- Insufficient metrics for storage systems affect the business cases and limit broader deployment.
- Lack of standards and models to support the complex interactions between various distributed technologies make it difficult to understand values and impacts.
- Deficient market structures do not adequately capture the multiple values of storage.
- Stakeholders have a poor understanding of the benefits of storage technologies.

Questions for Consideration

- How does distributed energy storage (electrical and thermal) interact, compare, and compete with other flexibility resources such as demand response, smart inverters, and smart charging of electric vehicles?
- What capabilities are needed from distributed energy storage devices to support increases in roof-top photovoltaics, microgrids, and other technological advances?
- What are the sensitivities of storage capabilities with different distribution topologies (more networked versus radial) and where is the optimal placement of these assets?
- What new business cases, regulations, or standards are needed to support the deployment and utilization of distributed energy storage?
- Which of these challenges are specific to the technology and which require more holistic considerations, as described in the Systems Perspective section of this document?

SYSTEMS PERSPECTIVE

To effectively and efficiently identify the R&D activities and initiatives that the DOE should focus on, it is necessary to take a comprehensive look across the various technology areas as well as a holistic system perspective of the grid. This broad perspective will help identify cross-cutting needs, reduce conflicting priorities, and ensure that a level playing field is considered when developing technology options.

The Distribution Sector Sketches in the previous section provide an overview of the issues, opportunities, and challenges associated with particular technology areas as they pertain to integration into the distribution system. It should be apparent that there are overlaps and similarities in the value proposition that a particular technology area can provide, in the synergies between several technology areas, and in the barriers that the technology areas face.

There is an array of R&D activities that can be pursued to overcome the challenges to grid integration as identified by the technology areas. The GTT developed a strategic framework (Figure 2) that organizes these activities into three interrelated domains - physical, informational, and knowledge - reflecting the systems nature of the grid. This framework and categorization will help guide discussions during the workshop. Each of these domains corresponds to a strategic focus that aims to increase the visibility, understanding, and flexibility of the electric power system. The logic behind these focus areas is that a modernized grid should be able to “see” an event, “know” what is happening, and “do” something appropriate in response – quickly and seamlessly.

In addition to the overlap and interactivity among these three technical focus areas, there are many institutional factors (markets, regulations, policies, standards, etc.) that underpin and influence the success of R&D activities and grid operations. The numerous institutional challenges associated with specific technical challenges must be addressed and integrated with the activities in the three strategic focus areas.

Integration of rooftop PV, electric vehicles, microgrids, transactive building loads, and other technologies in large amounts will fundamentally change how the distribution system must be planned and operated. Increased variability from PV generation, the movement and charging of electric vehicles, and the rise of prosumers (producers and consumers of electricity) will require increased distribution system flexibility and controllability. There are also opportunities for these technologies and assets to provide system flexibility to the bulk transmission system. Concurrently, it is vital that the right sensors, software, and communication technologies are available and in place to provide visibility of all these dynamic interactions to the appropriate parties to ensure a safe and reliable electric power system.

Additionally, improvements in the fundamental understanding of these dynamic interactions and the implications for operations and planning are needed. For example, end-user loads with power electronic drives generally have different response characteristics than traditional motor loads. Understanding these new response characteristics, their implications, and possibly modifying equipment as appropriate to provide more grid-friendly characteristics may be useful.

Due to the complex and interconnected nature of the system, grid modernization will require many innovations and advancement to occur simultaneously and successfully. A holistic systems perspective must be taken to consider the various technology options that can increase the flexibility, visibility, and understanding of the grid.

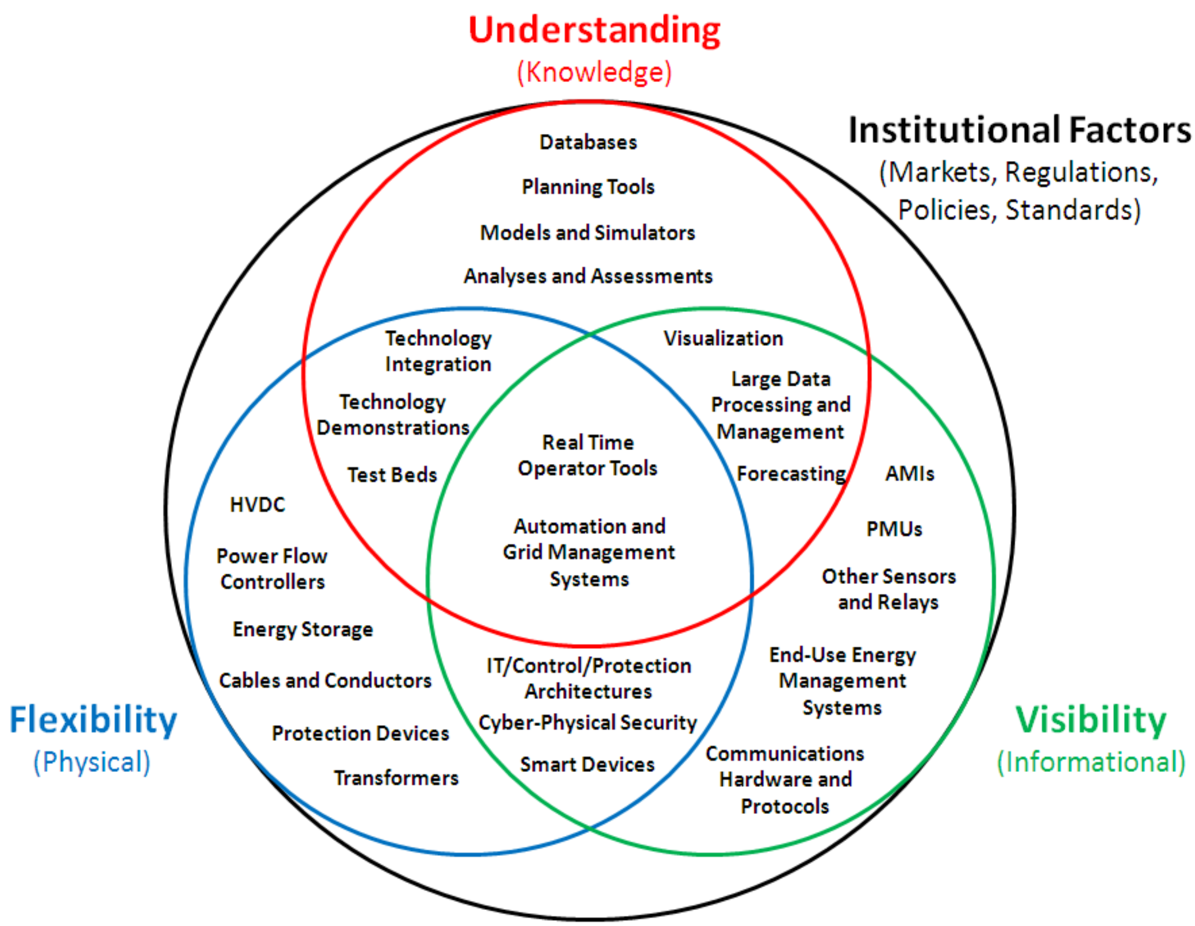

Figure 2 – Strategic Framework for Grid Modernization

Grid Flexibility

Introduction of new technologies into the distribution system brings challenges but also presents opportunities. Power electronics in end-use loads, PV inverters, PEV charging equipment, and energy storage devices could all be used to provide flexibility to the grid. Coordinated control of dispatchable distributed generation, aggregated building loads, and intelligent appliance are also within the portfolio of technology options.

Development of new technologies such as solid state transformers, power flow controllers, and advanced protection devices can also provide additional flexibility, especially with significant increases in distributed generation that may result in multidirectional flows in radial feeders. Utilizing more networked configurations for distribution feeders and DC buses are also options that can be considered for increasing grid flexibility.

These technologies and concepts require more in-depth discussions to consider the impacts to the design and operation of the various technologies integrating into the distribution system. The optimal combination of various technologies to leverage synergies and provide grid flexibility is also a worthwhile discussion.

Questions for Consideration

What R&D advances could be made in the physical domain (component technologies, inverters, power flow controllers, transformers, cable and conductors, protection device, etc.) to increase the flexibility and controllability of the grid? What are the characteristics and functionalities needed to address the challenges identified and ensure a safe, reliable, cost-effective system? More specifically:

- What are the key challenges facing the distribution grid in terms of component technology characteristics and their interactions (e.g., using night-time wind to recharge PEV's) that impact grid performance and system flexibility requirements to meet variability and uncertainty?
- How do you characterize, benchmark, and quantify the amount of flexibility needed to support the integration of various component technologies? What are the metrics?
- What new functionalities can component technologies provide to increase grid flexibility such as ancillary services?
- What changes are needed in the functional characteristics of component technologies to make them more grid-friendly?
- What control algorithms and hierarchies are needed to prioritize, coordinate, and aggregate component technologies and distributed assets to form virtual power plants or microgrids?
- What efficiency gains and performance improvements can be obtained from integrating technologies onto a DC bus?
- How would the flexibility characteristics and requirements differ or change between radial feeder and networked feeder designs?
- How can challenges such as voltage regulation, islanding, multidirectional power flow, and others at the distribution level best be met?
- What new protection mechanisms are needed to accommodate the integration of the various component technologies?

Grid Visibility

Lack of visibility and accurate, up-to-date information of grid conditions has been an important contributor to large-scale power disruptions and outages; examples include the Northeast blackout in 2003 and the Southern California blackout in 2011.[10] Very little visibility is currently available at the distribution level, raising serious concerns about ensuring system reliability with much more uncertainty and variability from the integration of new technologies (rooftop PV, PEV, etc.).

To effectively inform operations, visibility is required across multiple spatial scales (from the end-user load through the distribution substation and beyond) and at multiple time scales (from microseconds to hours and days). Advances in information and communication technologies such as PMUs and AMIs are becoming more widely available and provide the ability to observe grid conditions with significantly higher spatial and temporal resolution.

[10] Federal Energy Regulatory commission and North American Electric Reliability Corporation, "Arizona-Southern California Outages on September 8, 2011: Causes and Recommendations", April 2012.

Additionally, next generation sensors and relays may also be needed to adequately monitor the behavior and impacts of the various technologies integrating into the grid. Energy management systems for buildings, electric vehicles, and other software for end-use loads can also provide important information to distribution grid operators and grid management systems. New communications and control architectures will be required to handle and visualize the exponential increase in data, while consideration for latency issues with the higher temporal resolution and cyber-security implications will also be necessary.

Questions for Consideration

What R&D advances could be made in the informational domain (sensors and relays, AMIs, PMUs, end-use energy management systems, communications hardware and protocols, etc.) to increase the visibility and controllability of the grid? What are the characteristics and functionalities needed to address the challenges identified and ensure a safe, reliable, cost-effective holistically integrated system? More specifically:

- What are the requirements for the measurement and communication of data from the various technologies integrating into the grid to ensure reliability?
- Are there fundamental improvements in communication hardware and protocols necessary to ensure data is timely and secure?
- What type of information should be provided to the various technologies being integrated to support controllability in the distribution system?
- How can deployment of sensors, including AMI, best be implemented on distribution feeders? What data, and at what rates, should be targeted?
- How should data be made accessible to utilities, customers, and others?
- What is the role of the cloud in ensuring seamless connectivity between component technologies, the distribution grid, and potentially transmission operators?
- How do we ensure that the information, control, and protection architectures are well integrated and aligned?
- If the information is wrong and/or communication fails, what will be the impact to the various component technologies? What can be done to mitigate adverse impacts?

Grid Understanding

Improved understanding of the grid is necessary to make sense of the data that comes from increased visibility and to inform a control action that can be executed through increased flexibility. The uncertainty and variability introduced by the integration of new technologies requires fundamental improvements to tools, models, and simulators that can accurately reproduce observed behaviors and inform better operations and planning. Currently, the development of these technologies for the distribution system has been insufficient.

Planning and operation of the electric power system spans multiple scales in space (facility, feeder, service area, state, region, interconnect) and time (decades to microseconds). The development of tools that appropriately nest and link from one scale and dimension to the next in order to enable system-wide situational awareness and proactive system management is needed. Good knowledge of how technologies and conditions evolve and impact the system over these scales and dimensions is required for grid modernization.

A modernized grid should have the capability to identify and respond appropriately to potential conditions that could lead to disruptions. Databases and advances in computation and algorithms are also needed to support this capability and the development of tools, models, and simulators. Analyses and assessment of the various technologies to be integrated along with demonstrations in test beds will also support improved understanding of the grid.

Questions for Consideration

What R&D advances could be made in the knowledge domain (databases, planning tools, models and simulators, analyses and assessments, etc.) to increase the understanding and controllability of the grid? What are the characteristics and functionalities needed to address the challenges identified? More specifically:

- What operation and planning tools are needed to enable effective integration under conditions of high variability—both supply (e.g. PV) and load (e.g., EV, DR)—and high uncertainty?
- What additional databases, such as load, weather, technology deployment, distribution system layout, and others, will be needed to support operations and planning?
- How do we ensure that models of various technologies are accurate and that simulations produce credible results?
- How do we develop tools and simulators that can span the multiple scales and multiple dimensions of the power system?
- How can current grid models be best extended and validated in order to address the rapid introduction of new technologies into the grid, particularly at the distribution system level?
- What can be done to generate (near real-time) data on the specific costs and benefits, both direct and indirect, of each technology—PV, CHP, PEV, etc.—or service—DR—in order to develop effective market valuation around it?
- What advances in mathematics and computation (e.g., stochastics, parallel processing) can be leveraged in the development of tools?
- How do we ensure that the large amounts of data from increased visibility can be accessed in real time and won't overwhelm the tools?

Institutional Factors

As new technologies are being deployed and integrated into the grid, their eventual success or failure will depend on having the institutional support for those technologies. Market rules, regulations, and policies can significantly impact the viability of business models and the lack of a trained workforce can also hamper success.

Public utility commissioners, regulators, and consumers must be empowered to make educated decisions that weigh the benefits of adopting a particular technology along with the costs. Educational and analysis tools that can support these decisions should be based on a level playing field that balances the various technology options and regional policy goals.

Tools that can help resolve designs of new markets and policies will also provide significant value in overcoming the institutional challenges associated with technology integration. For example, ancillary services that can be provided from distributed generation, PEV charging, or DR may not be recognized or valued. It is essential to understand the interplay between these technological and institutional factors. Regulations and standards for the interoperability of the multitude of technologies are also needed.

Questions for Consideration

What advances could be made in the institutional domain (markets, regulations, policies, standards, etc.) to increase the deployment of R&D successes? What analysis and educational tools are needed to address the challenges identified and ensure a safe, reliable, and cost-effective system? More specifically:

- What analytical tools are needed to value the full range of costs and benefits of supply and demand on the distribution system so that decision-makers can appropriately structure policies and regulations for effective market operation?
- What regulations need to be in place to ensure that the technologies deployed on the distribution system won't adversely impact the operation of the transmission system?
- Which entities should be responsible for adopting/setting/enforcing these regulations?
- How do we have states and utilities expand adoption of interconnection standards and institute new policies to allow the flow of surplus energy from self-generation back to the grid?
- What type of markets will be needed to enable effective operation of the various technologies and assets on the distribution system?

POINT OF DEPARTURE

Approaching the Workshop

The purpose of this DOE Action Plan is to begin the process of developing a comprehensive research roadmap for grid integration at the distribution level. This process involves engaging with key stakeholders to identify opportunities and challenges, R&D needs, and priorities for action spanning the near-, mid-, and long-term.

The Distribution Workshop is a critical step in the development of a roadmap that accurately targets the identified opportunities and challenges. The advice and proposals gleaned from the workshop will assist the DOE in making decisions on how to refine and implement a research roadmap. This will likely be released in draft form with a formal request for information, which will be published in the Federal Register. The results of the workshop and the road mapping process will help reinforce the broader efforts of the Grid Tech Team and enable DOE to support research and development of critical solutions to achieve a 21st century distribution system.