Electricity Advisory Committee

MEMORANDUM

TO: **Honorable Patricia Hoffman, Assistant Secretary for Electricity Delivery and Energy Reliability, U.S. Department of Energy**

FROM: **Electricity Advisory Committee (EAC)**
Richard Cowart, Chair

DATE: **March 27, 2015**

RE: **Recommendations on Smart Grid Research and Development Needs**

Overview

The Smart Grid is envisioned to provide the enhancements to ensure higher levels of security, quality, reliability, and availability (SQRA) of electric power; to improve economic productivity and quality of life; to improve the efficiency of and asset utilization in the power system; to reduce environmental impacts and facilitate the integration of renewable resources and variable net demand; to enhance customer choice and control; and to ensure safety. Achieving this vision will require careful policy formulation, accelerated infrastructure investment, and greater commitment to public/private research, development, and demonstration (RD&D) to overcome barriers and vulnerabilities. The RD&D required is substantial and will require participation by many organizations and institutions including a major new multi-year federal commitment to support the development of information and control systems that integrate dynamic transmission and distribution and distributed energy technologies into system planning and operations. In this paper USDOE's Electricity Advisory Committee offers an overview of the Smart Grid's RD&D needs and areas where the Department of Energy can offer the most critical support, through its Research, Development and Demonstration programs.

Utility objectives rely on technology as an enabler of the future grid

Utilities and their regulators will be faced with the challenge of maintaining utility scale electricity production and delivery, while also accommodating policy imperatives that embrace end-user electricity production and a steady move towards deploying carbon free sources of electricity production. Technology is an enabler.

EAC
Electricity Advisory Committee
U.S. Department of Energy

Efficiencies can be gained if the following objectives can be met as utilities continue to invest in the evolution of their systems:

- *Support active participation by consumers:* The smart grid should engage customers and the increasingly intelligent energy technologies in their homes and businesses. The ready availability of information on the Internet of the best, least expensive, most unique, and most customer relevant products and services has produced increasing customer expectations. The power industry is not immune to these trends. The smart grid customer will expect technology to efficiently manage their comfort and energy choices, to be informed regarding and experience a reduced incidence of service interruptions, and to be offered choices for controlling and modifying the way they use and purchase electricity. They increasingly will expect and have choices, incentives, and social media interactions regarding the adoption of intelligent devices and modifying their purchasing patterns and behavior. These choices help drive new technologies and could fundamentally change power system operations.
- *Support new products, services, and markets*: The smart grid should be able to support a market system that provides cost-benefit tradeoffs to consumers by creating opportunities to bid for competing services. As much as possible, regulators, aggregators and operators, and consumers can modify the rules of business to create opportunity against market conditions. A flexible, rugged market infrastructure exists to provide different service levels of electricity reliability and quality that are tailored to meet individual customer needs. For some consumers this may entail ensuring continuous electric service and reliability, while also providing revenue or cost reduction opportunities for market participants.
- *Accommodate and optimize the use of intelligent devices that reside at different points within the grid:* While the grid of the future is likely to contain billions of intelligent devices, the architectures to control or coordinate the operation of these devices consistent with system reliability is not yet certain. Some central station generation and network equipment is likely to continue to be centrally dispatched. Control over other devices and end uses could be distributed to substations and micro-grids to address market structure, reliability or latency concerns. Other devices and end uses may transact directly with one another creating a form of distributed coordination through localized markets or so called, master controllers.[1] These controllers would control local distributed energy resources (DERs) and utilization in buildings, campuses or industrial parks by communicating with one another as well as with the grid.[2] Finally, some devices could independently respond to local grid conditions without any outside direction, in much the same way that a school of fish may change direction with each individual responding to its neighbors without any centralized leadership or control.

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[1] Master Controllers need not be sophisticated control devices, but will vary considerably depending on the application. In a simple residential photovoltaic installation they may merely be an intelligent inverter. In larger buildings they can be Energy Management Systems operating end-uses, electrical and thermal storage and guiding participation in Demand Response programs.

[2] Distributed energy resources refer to distributed generation, demand response, energy storage, electric vehicles, and microgrids.

- *Make appropriate use of open standards:* Standards will be key to ensuring the interoperability of the different power and information systems needed to maintain the power grid. The continued ability of this nation to lead and influence standards development will be a major factor in the ability of U.S. companies to participate in and benefit from large scale global initiatives to build and modernize power systems.
- *Integrate new and legacy technologies:* The smart grid will develop over time. It requires a clear roadmap and transition path to the future. At each point along the way next generation systems will have to interoperate with legacy systems.
- *Provide power quality for the digital economy*: The smart grid, at its essence, must continue to provide reliable power, power that is "clean" and disturbances are minimal. Global competitiveness demands relatively fault-free operation of the digital devices that power the productivity of our 21st century economy. System models are needed which support integration of DERs – if it isn't planned, it will never be integrated.

Why does the Department of Energy need to fund R&D in smart grid technologies?

In order to assure that the Nation's citizens can avail themselves of all of the benefits of a Smart Grid, the Federal Government, through the Department of Energy, must act as a catalyst in funding the necessary Research, Development and Demonstration of advanced technologies. Electric Utility Customers and to a lesser extent the Utilities themselves are the benefactors of these advanced technologies and one might question why utilities do not eagerly embrace the prospect of providing adequate funding to do so. By its nature, the electric utility is often resistant to rapid change. The electric power delivery system (the grid) is a vast and complex network comprised of a range of assets including transmission lines, substations, distribution feeders and related equipment representing one of the largest capital investments of any industry in the U.S. Ownership is complex and consists of various structures with equally complex and conservative governance. Where these entities are regulated, they are often subject to a state regulatory regime where investments are understandably scrutinized, and must be found to be prudently incurred and be "used and useful" in serving the needs of that utility's customers.. Under this test R&D must usually stand the test of providing specific benefits to a utility's customers or run the risk of having the investment disallowed, In addition the nation is served by over 2700 individual utilities who are each reluctant to embrace the burden of individual technology development.

Electrical Apparatus manufacturers are the other likely benefactor from R&D in the Smart Grid Space as it provides more products for them to sell. And they do some R&D. However, the market for Smart Grid technologies is difficult to navigate for the reasons stated above and where important technologies like a computer for a control center only face a market of a few hundred potential buyers, the incentive for manufacturers to invest is not sufficient. In particular for larger Smart Grid technologies like those, for example, which embody advanced power electronic devices most U.S. Utilities lack the size, financial strength and mandate to undertake the research, development and demonstration of new technologies. In addition, they are no longer able to maintain properly equipped laboratories or test facilities. Although the industry does undertake collaborative research through the Electric Power Research Institute (EPRI), industry funding of EPRI is voluntary and EPRI's research spending has declined sharply since the early 1990's.

Utilities are also confronting the costs of securing the electric system against cyber and physical attacks; adding new pollution control equipment to existing generating units; and maintaining system stability and reliability while replacing aging assets and facing potential declines in revenue growth resulting from structural shifts in the US economy, increasing end-use energy efficiency, as well as regulatory and market innovations that emphasize the value of demand-reducing resources,

The Department of Energy can offer critical support through education, and supporting research, development and demonstrations.

The Department should educate policy makers, regulators and investors on the possibilities emanating from the deployment of advanced technologies to produce and transmit, distribute, store and use electricity at both a utility scale and directly at the consumer's premises. The Department should support research and the development and demonstration of the most promising approaches. It also should support dialogue among market participants to advance the development of common standards and architectures that can accelerate cost-effective grid modernization, ensure security, and enable interoperability. While the development of a smarter power system will involve investment decisions by thousands of market participants (from utilities to end-users), and will be influenced by the evolution of technology and economic guidance and incentives provided by state and federal regulators and policy makers, ongoing engagement in the development of common standards and architecture can help reduce costs and risk.[3] Another appropriate role for DOE is to educate decision makers by illustrating capabilities (through proof of concept projects and investments in promising technologies) and sponsorship of interface standards to enable the interaction between the technologies deployed in the smart grid. There are a number of areas where the Department can support utilities, regulators and policymakers in their efforts to guide the development of the grid, including supporting:

- characterization of the impacts of the changing physical topology on the power system including various configurations of central generation, bulk energy power, integration of transmission and distribution planning and operations, dynamic control of transmission and distribution topologies, distributed energy technologies (including distributed generation, responsive demand, and storage) and microgrids. This includes assessment of the impact and benefit of wide scale use of variable resources including wind and solar power generation on electric power system reliability and greenhouse gas reduction;

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[3] Regulators in New York and California have initiated proceedings that could result in distribution companies taking on the roles of a Distribution System Platform Provider or Distribution System Operator responsible for facilitating the efficient integration of distributed energy technologies. Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision, Order Instituting Proceeding, New York Public Service Commission Case 14--M-0101 (April 25, 2014); In the Matter of Order Instituting Rulemaking Regarding Policies, Procedures and Rules for Development of Distribution Resource Plans Pursuant to Public Utilities Code Section 769, Order Instituting Rulemaking, Public Utilities Commission of California Rulemaking 14-08-013 (August 20, 2014).

- development, demonstration and deployment of sensors, communications, protection, control, data management, and information systems to manage a more dynamic power grid and the integration of distributed energy technologies;
- development and demonstration of new computational ability, new algorithms to utilize the high performance computing technologies and operational analytics
- development and identification of applications of various advanced technologies which promise to enhance the functionality and performance of the grid;
- review and reporting of potential cyber and physical security threats, and recommendations for security improvements;

DOE research, development and demonstration results are critical to address power industry challenges.

The appropriate application of key learnings and deployment of proven technologies will be essential in addressing the power industry's key long- and near-term challenges, by: assuring stable and reliable communications; continuing to assure long term reliability; ensuring physical and cyber security; and enabling both new supply, storage and end – use resources to be utilized in an integrated manner. Examples include:

- *Natural disaster impacts*: Concern is growing regarding the electric infrastructure's vulnerability to widespread blackouts and power outages resulting from natural disasters. Recent examples include super storm Sandy, hurricane Katrina, the October 2011 storms in the northeastern United States, and the tsunami and resultant Fukushima Daiichi nuclear disaster in Japan. In each case, the electric infrastructure suffered considerable damage and left citizens without power and often without clean water, food, and fuel for heating or transportation. As an additional consequence of the digital age, the communication now often provided by cell phone technology failed as well, because many cell towers were without power, and telephone users were largely without power to charge their phones (except for a few with solar chargers).
  Investment efficiency: Smart grid strategies may be able to significantly improve utility load factors and asset utilization. However, more study is needed to show potential improvement. This could play a key role in helping utilities manage new investment requirements. The average U.S. generation capacity factor has been below 50 percent for the last decade.[4] Many transmission and distribution facilities have average use rates that are even lower. In order to enable greater variability in supply while still meeting consumer needs innovative techniques are needed to allow greater response by consumers and their energy technologies to power system conditions. In the electric industry, state regulators have been reluctant to expose consumers to dynamic pricing (due to political reasons), thus limiting the consumers' propensity to conserve at times of peak demand. The recent court decision on FERC Order 745 further complicates the integration of DR in the wholesale markets.

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[4] U.S. Energy Information Administration, Electric Power Annual 2009, (April 2011), Table 5.2, P. 48.

Cyber security: A recently released National Academy of Sciences report (Terrorism and the Electric Power Delivery System, National Research Council, 2012) identified what is at stake in protecting the power system from a cyber or a combination of cyber and physical attacks. The report suggests steps including the use of sensors and development of micro-grids to reduce the grid's vulnerabilities. While it is doubtful that microgrids by themselves will provide sufficient "firewalls" against cyber-attacks, work on the smart grid has helped lead the way in building cyber-security into processes and grid technologies and in developing comprehensive cyber-security architecture.[5]

- Integrated DERs including electric vehicles at scale and accommodation of future carbon policies: For example, the European Union estimates that meeting current European targets could result in a reduction of greenhouse gas emissions by 80% by 2050 (Roadmap for Moving to a Low-Carbon Economy in 2050, European Commission, 2010). This could require largely decarbonizing the electric sector while meeting significant new loads in a comparatively short time. To support this, electric utilities would need the infrastructure to support local load pockets and eventually large scale adoption of DERs and electric vehicles. These requirements could arise more rapidly than would be anticipated based on historical experience. For example, a recent McKinsey study found that the cost of fully installed residential solar photovoltaic system could fall from more than $4 per Watt peak in 2008 to $1 per Watt peak in 2020.[6] Smart grid technologies would enhance the ability of the grid to "host" increasing amounts of these and other distributed technologies by providing visibility and control needed to manage what will be a more complex system. It should be understood, however, that some form of the traditional Transmission, Distribution, and Generation resources will be needed to support the normal operation of Distributed Energy Resources at both peak and off-peak conditions.
- *Integration of responsive demand:* Intelligent devices, such as thermostats that automate customer preferences for savings and comfort, smart appliances, and building and home energy management systems are poised to take advantage of advances in data analytics and the falling cost of digital technologies to provide broader and deeper levels of demand participation. Google's $3.2 billion purchase of Nest and Apple's announcement of its HomeKit platform for energy applications are part of a growing supplier base that includes utilities and energy service companies, technology and controls companies, cable and telecom providers, big box retailers and a range start-up firms. For most uses of electricity, intelligent devices create an opportunity to take advantage of the thermal inertia available in heating and cooling buildings, heating water, and refrigeration or flexibility in the timing of power uses for pumping loads, batch processes, dishwashers, and charging electric vehicles and other devices. Automated choice engines that integrate energy using devices with power markets or system operations could identify the least expensive times to use power, implement savings strategies, and match

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[5] Smart Grid Interoperability Panel, Cyber Security Working Group, *Guidelines for Smart Grid Cyber-Security,* NISTIR-7628 (Washington, D.C. National Institute of Standards and Technology, 2010)

[6] K. Aanesen, S. Heck, and D. Pinner, *Solar Power: Darkest Before the Dawn* (McKinsey & Company April 2012).

individual preferences for comfort and services. Unlike existing demand response programs that may be called upon a few times a year, if appropriately integrated into system operations intelligent devices could:

- Expand demand participation and customer savings by lowering the cost of building energy management for commercial and industrial customers; providing choice and control to millions of residential customers; and helping avoid wasted energy by cooling, heating, and lighting people and their activities while limiting energy use in unoccupied spaces;
- Improve utility asset utilization on a continuous basis, not just for a limited number of peak demand events;
- Facilitate the integration of renewable and variable resources and loads by offsetting variations, reducing the need for electrical storage, and moderating the ramping of generation; and
- Provide system operators location-specific, rapidly responding options to address reliability events that occur within an operating day.

Operational efficiency and workforce management: Electric utilities need to continue improving operating efficiency while also attracting and training large numbers of key personnel. A 2011 Center for Energy Workforce Development survey found that:

"For those positions considered critical, skilled utility technician and engineering (excluding positions in nuclear), the analysis indicates that by 2015, 36% may need to be replaced due to potential retirement or attrition, with an additional 16% to be replaced by 2020 — almost 110,000 employees in positions identified as the most critical by industry."[7]

The integration of intelligent sensor, communication, control, and information technologies into utility operations will be important to improving business processes, the use of workers with new skills, and overall operating efficiency.

The DOE should continue to address market gap for critical information and control systems

While, there has been and continues to be robust RD&D in discreet areas of smart grid technologies, the necessary information and control systems do not now exist for the efficient integration dynamic transmission and distribution topologies and distributed energy technologies. Such systems will be critical to the continued efficient and reliable operation of the power system. However, the potential market for such systems consists of a limited number of transmission and distribution system operators. As a result, timely development of such systems may not occur without significant new federal RD&D investments. The EAC notes that the Department has taken steps to begin addressing this challenge through its Grid Tech Team and ARPA-e's GENI program. However, given the importance and scope of the challenge, more is needed. The EAC appreciates that the Department previously sought funding for innovation hubs that might have addressed this challenge. We find that addressing this challenge should continue to be a very high priority.

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[7] Center of Energy Workforce Development, *Gaps in the Energy Workforce Pipeline* (2011).

Additionally, the DOE can perform a critical educational role to policy makers, utility regulators, end-consumers and investors in the field of electricity production and delivery. Technological innovation and policy mandates are driving enormous change and it will be challenging for utilities and their regulators to manage through this change in a manner that maintains cost effective, reliable electrical service. This paper represents one action by the EAC to review and make recommendations regarding the Department's programs for meeting this challenge.

Electricity Advisory Committee Survey on Smart Grid Research and Development

In conjunction with the development of this work product, the Electricity Advisory Committee conducted an informal survey of its membership on federal investments in Smart Grid R&D. The survey was intended to gain insights on the Committee's views regarding Research and Development needs relative to the Smart Grid and to gauge members' views on funding priorities across the various stages of research, development, demonstration and commercialization. The survey also sought to elicit input from EAC members on how DOE might best allocate investment resources across the electric utility value chain and among various technologies.

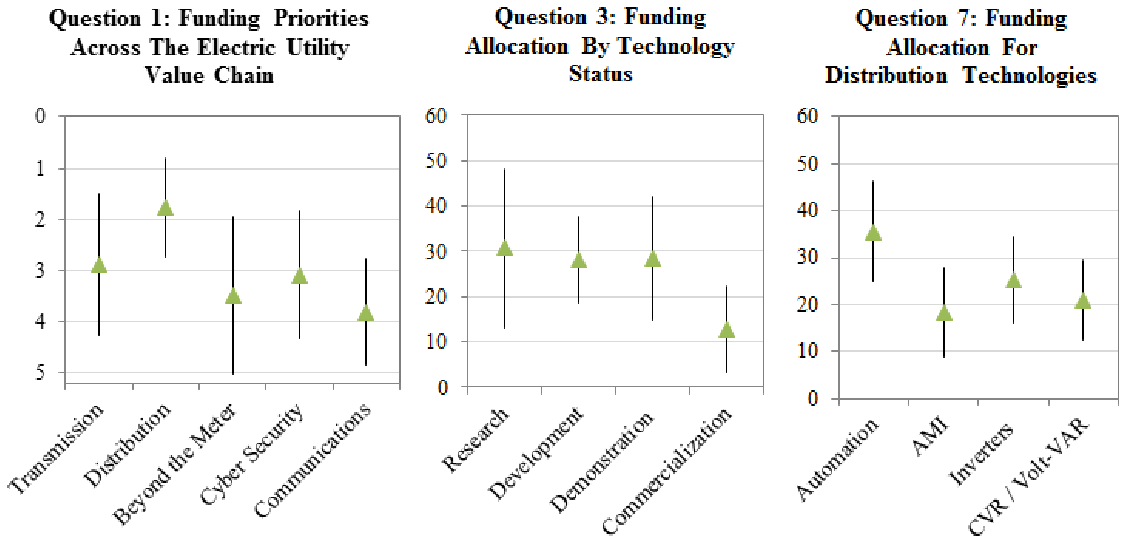

Figure 1 Sample results from the R&D survey of EAC Members conducted in January 2015. The mean value plus and minus one sample based standard deviation is presented for each option. The full text of each question and similar summaries of each question are available in the Appendix to this document.

The results of the survey reflected significant variation across the responses from the EAC members with a broad distribution in the funding allocations and priorities assigned to each option. While there was no clear consensus on the questions that were posed, a few key trends did emerge. In particular, the Committee placed a higher priority for DOE investment at the distribution level (see question one above) and distribution automation received the highest relative allocation among the distribution technology in the survey (see question seven above). Also, the allocation of funds throughout the stages of technology readiness was fairly even with the exception of later-stage investments in commercialization in diffusion which received relatively smaller allocations on average (see question three above). The full text of each question and a summary of all the responses are presented in the Appendix to this document.

Transmission Lines and Substations

The high-voltage transmission system is the "backbone" of the power delivery system. It transmits very large amounts of electric energy between regions and sub-regions. Transmission system equipment fails and causes power outages much less frequently than distribution equipment. But when transmission equipment fails, many more customers are affected, and outage costs can be much higher, compared to the impact of a distribution equipment-related outage.

Status of technologies ready for adoption

The following described technologies have undergone significant research and development and are now available for commercial use, but have not been widely deployed. As with any technology, advances are continuing in most areas. The adoption of these technologies by the electric utility industry are limited, typically by the business cases that include the cost/benefits analysis each capital investment must undergo before implementation.

Adoption of Dynamic Thermal Circuit Ratings (DTCRs) requires business case development

Dynamic rating and real-time monitoring of transmission lines are becoming important tools to maintain system reliability while optimizing power flows. Dynamic ratings can be considered a low-cost alternative for increased transmission capacity. Dynamic ratings are typically 5 to 15% higher than conventional static ratings. Application of dynamic ratings can benefit system operation in several ways, in particular by increasing power flow through the existing transmission corridors with minimal investments.

Dynamic rating increases the functionality of the Smart Grid because it involves the monitoring of real-time system data that can be used in various applications:

- Real-time monitors yield a continuous flow of data to system operations – line sag, tension or both, wind speed, conductor temperature, etc. – traditionally not available to operators.
- Monitored data can be processed to spot trends and patterns.
- Real-time monitored data may be turned into useful operator predictive intelligence (e.g., critical temperature and percent load reduction needed in real time).

However, while additional research may be needed to fully integrate DTCRs with future control schemes, a more robust business case for the application of this technology must be developed so that more utilities adopt this technology. System planners are concerned that you cannot count on the qualifying conditions that offer the ability to benefit from DTRC to be present when DTRC may be needed. Therefore when doing the business case, you almost always have to plan around, or even plan out the corridors that could benefit from DTCR.

Increase Capabilities of Fault Current Limiters or Short-Circuit Current Limiters (SCCLs)

Short-circuit current limiters (SCCL) or fault current limiters are a family of technologies that can be applied to utility power delivery systems to address the growing problems associated with fault currents. The present utility power delivery infrastructure is approaching its maximum capacity and yet demand continues to grow, leading in turn to increases in generation. The strain to deliver the increased energy demand results in a higher level of fault currents. As a result, more SCCLs are needed. However additional development is needed to reduce their cost and, physical size. SCCLs fall into two categories: superconducting devices and non-superconducting devices. Superconducting SCCLs are either resistive or inductive. In a resistive device the current passes through the superconductor and when the current increases, the superconductor quenches. In the inductive device, the simplest form is a transformer with a closed loop superconducting secondary. Non-superconducting devices can be simple inductors or variable resistors. The power-electronics-based SCCL is designed to work with the present utility system to detect a fault current and act quickly to insert impedance into the circuit to limit the fault current to a level acceptable for normal operation of the existing protection systems.

Cost reduction of Transmission Power Flow Control Technologies needed.

This area of technology development could also be called Power Electronics Based systems. They are also known in the industry as Flexible AC Transmission (FACTS) technologies. There are a number of these technologies that are commercially available today. These all incorporate power electronics and can be applied to the transmission system. These include both the control and operation of the power system and applications that will extend eventually to transformers themselves.

These types of devices can be used for power flow control, loop flow control, load sharing among parallel corridors, voltage regulation, enhancement of transient stability, and mitigation of system oscillations. They include the thyristor controlled series capacitor (TCSC), thyristor controlled phase angle regulator (TCPAR), static condenser (STATCON), and the unified power flow controller (UPFC). AEP installed the first UPFC at its Inez substation in eastern Kentucky in 1998. While these technologies are more than 20 years old and well understood, there are almost always considered too expensive when compared to simply building more assets. Accelerating development of advance power electronics so as to dramatically reduce the cost of FACTS devices should remain a priority.

The Department through ARPA-E also has supported research and the development of new low cost technologies to control transmission line power flows and approaches for dynamically managing the topology of the transmission grid to promote greater utilization of the transmission system. However, even at a reduced cost, their installation will force a more complicated optimization schema – this will also need to be solved at the same time. Distributed series reactors, sometimes called “smart wires” that were funded by ARPA-E, are an example of potential advancement in this regard.

Accelerate Deployment of Voltage Source Converters

Voltage Source Converters (VSCs) are self-commuted high voltage direct current (HVDC) converters and contrary to “traditional” HVDC converters do not have to rely on synchronous machines in the AC system for its operation. The increased controllability improves harmonic performance and provides VAR support. VSCs permit power flow to be reversed without reversing the polarity of the cable, thereby enabling the use of extruded cables (cables insulated with extruded polyethylene-based compound such as XPLE). It makes undergrounding (cables instead of overhead lines) more attractive. More VSC's are needed in the North American power system.

Advanced analytics and visualization applications needed to maximize use of Phasor Measurement Unit data

Phasor measurement units (PMUs) or synchrophasors provide real-time information about the power system's dynamic performance. Specifically, they take measurements of electrical waves (voltage and current) at strategic points in the transmission system 30 times per second. These measurements are time stamped with signals from global positioning system satellites, which enable PMU data to be time-synchronized and combined to create a comprehensive view of the broader electrical system. Widespread installation of PMUs, which is occurring now, will enhance the nation's ability to monitor and manage the reliability and security of the grid over large areas.

PMUs can provide system operators with feedback about the state of the power system with much higher accuracy than the conventional SCADA systems which typically take observations every four seconds. Because PMUs provide more precise data at a much faster rate, they can provide a much more accurate assessment of operating conditions and limits in real time. However, at this time, the actual visualization of this data and real-time feedback to operators is limited by available analytical tools for use in operating transmission systems (See Advanced Grid Modeling in the following section).

Accelerate Development of Intelligent Electronic Devices (IEDs)

Intelligent Electronic Devices (IEDs) encompass a wide array of microprocessor-based controllers of power system equipment, such as circuit breakers, transformers, and capacitor banks. IEDs receive data from sensors and power equipment, and can issue control commands, such as tripping circuit breakers if they sense voltage, current, or frequency anomalies, or raise/lower voltage levels in order to maintain the desired level. Common types of IEDs include protective relaying devices, load tap changer controllers, circuit breaker controllers, capacitor bank switches, recloser controllers, voltage regulators, network protectors, relays etc. Considerable development is needed to expand the family of IED's available and, in turn, further enhance the functionality of the grid.

With available microprocessor technology, a single IED unit can now perform multiple protective and control functions, whereas before microprocessors a unit could only perform one protective function. A typical IED today can perform 5 to 12 protection functions and 5 to 8 control functions, including controls for separate devices, an auto-reclose function, self-monitoring function, and communication functions etc. It can do this without compromising security of protection – the primary function of IEDs.

Technologies requiring additional research, development, and demonstration

The following technologies are undergoing significant research and development and in some cases are in very early stages of commercial use. In several cases, the R, D&D required to advance transmission technologies is currently being addressed by the USDOE's ARPA–E efforts in the GENI program. GENI is an acronym for Green Electricity Network Integration. The program's mission is to modernize the way in which the Nation transmits electricity through advances in hardware and software to enable greater control over power flows in order to better manage peak demand and cost.

Continue investment to promote Advanced Power Electronics for Transmission Applications

HVDC converters and other controllers are based on Power electronic semiconductor devices. These devices exploit the properties of semiconductor materials, principally silicon, germanium, and gallium arsenide. Semiconductor materials can be manipulated by "doping," the addition of impurities, and can be controlled by the introduction of an electric field, light, or pressure. Power semiconductor devices are those intended for high-current and/or high-voltage applications. Silicon (Si) is the most widely used material in the manufacture of semiconductor devices. It has low raw material cost, requires relatively simple processing, and offers good temperature range. Other, more advanced devices are being researched which could reduce the cost and increase the functionality of converters. A new set of potentially "game-changing" switches has evolved. These switches fall into the category of "wide band gap" semiconductors. Among these, Silicon Carbide (SiC) and Gallium Nitride (GaN) have increased in reliability and dramatically decreased in cost. They hold a promise for significantly increased high-value applications across the electric utility industry in power generation, delivery, and end use and should be actively supported by the DOE.

Advanced Electric Energy Storage

Bulk storage is one of the major limitations in today's "just in time" electricity delivery system and one of the great opportunities for Smart Grid development in the future. Only about 2.5% of total electricity in the U.S. is now provided through energy storage, nearly all of it from pumped hydroelectric facilities used for load shifting, frequency control, and spinning reserve. The Department has supported research and the initial development of storage technologies ranging from improved battery chemistries to new approaches for compressed air storage.[8] However, the cost and performance of today's electric energy storage is well below that which will be needed to witness wide-spread adoption. DOE needs to continue and enhance research on new storage technologies, the development of early stage commercial technologies and the demonstration of various applications.

Investment in Robotics and Unmanned Aerial Vehicles can reduce inspection cost and increase safety.

EPRI states, "With over 300,000 km (186,000 miles) of transmission lines in the U.S., transmission line inspection is a costly, and sometimes dangerous, proposition. Robotic transmission line inspection involves various technologies that inspect transmission lines (as well as substation equipment and potentially distribution equipment) using robots rather than humans. The idea is to reduce inspection costs and improve safety by using robots in potentially

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[8] Refer to: "A National Grid Energy Storage Strategy: Offered by the Energy Storage Subcommittee of the Electricity Advisory Committee," January, 2014

hazardous environments."[9] Likewise, the use of unmanned aerial vehicles (UAVs), either fixed wing or rotary wing, is being studied today in conjunction with the FAA for use in facility inspections. This technology also has potential to assist in the quick evaluation of facilities after a major storm, which would then allow for more efficient, and safe, restoration efforts.

Transmission Operations requires Advanced Grid Management Tools

Transmission system operators (TSOs), which is inclusive of traditional utility transmission owners/operators, independent system operators (ISOs), and regional transmission organizations (RTOs) and others (all referred to as TSOs) are making investments in an increasingly robust communications infrastructure as well as an enhanced analytical and forecasting capability. These investments are being made in response to requirements for TSOs to incorporate increasing functionality in order to maintain reliability, meet load growth, and to comply to new regulations which are increasing grid compliance with Federal Energy Regulatory Commission (FERC) rules, increasing the use of distributed resources, demand response and energy efficiency. At the same time, market operations are becoming increasingly more complex, the threat of cyber security is increasing, and pressures are continuing to mount to maintain costs and improve the use of assets.

A number of these investments were made as part of sustaining core capabilities even before the nation began to evolve the concept of a "Smart Grid." For example, the developments of techniques for real-time simulation of transmission operations and enhanced visualization have been under development since the 1990s. Today, they are considered part of the Smart Grid, but would have simply been viewed as necessary improvements a decade ago.

In order to further the ability of TSOs to take advantage of these investments, there is significant research and development underway in the area of AGM, or Advanced Grid Management. This involves the areas of data analytics, advanced mathematical algorithms, data management, and others that will allow system operators to use "faster than real-time data" to manage the transmission system.

Accelerate Development of Advanced Sensors and other Intelligent Electronic Devices

As noted above, with the increased installation of IEDs, specifically equipment monitors, and sensors, transmission asset owners will have the ability to monitor, in real time, the condition of their transmission line and substation assets. The transmission system of the future will utilize a synergistic concept for the instrumentation of electric power utility towers and substations with sensor technology designed to increase the efficiency, reliability, safety, and security of electric power transmission. This will allow for multiple applications, including:

- *Safety and Reliability*: The application of sensors for transmission line or substation components will allow for the monitoring and communication of equipment conditions. Information that a transmission line or substation component is in

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[9] Insert reference to EPRI website.

imminent risk of failure will enable actions to be taken to repair the equipment and minimize the outage impact as well as address the safety of utility personnel.

- *Outage Response*: If the condition of a component or system is known to be at risk, personnel can be deployed to prevent or minimize an outage.
- *Condition-Based Maintenance*: Knowledge of component condition enables maintenance actions to be initiated at appropriate times rather than relying on interval-based maintenance.
- *Asset Management*: Improved knowledge of the condition of equipment and stresses that they have been subjected to will allow managers to better manage the assets. Sensor data used together with historic performance information, failure databases and operational data allows better allocation of resources.
- *Increased Asset Utilization*: As noted in the previous section, the rating of transmission components is influenced by a range of factors such as ambient weather conditions, loading history and component configuration. In order to address this complexity, static ratings are usually based on conservative assumptions of these factors. Higher dynamic ratings can be achieved with more precise, real-time knowledge of the asset's condition.
- *Forensic and Diagnostic Analysis*: After an event occurs, there is limited information to understand the root cause. Sensors allow the capture of pertinent information in real time for a more rigorous analysis.
- *Probabilistic Risk Assessment*: Increased utilization of the grid is possible if contingency analyses are performed using probabilistic, rather than deterministic, methods. To use probabilistic methods, knowledge of the condition of components and the risks they pose are needed.

Continued Development of Advanced HVDC Technologies

Several new HVDC technologies could be developed which would further enhance the functionality of that technology. First will be a family of devices which facilitate flow control and for direct voltage control in a meshed HVDC grid as well as technology which offer better overall control and protection of HVDC grids. Companion developments would address technical requirements and specifications of state-of-the-art HVDC switching equipment. Other developments include:

  - Fixed series capacitors
  - Large capacity (>60 kA) circuit breakers
  - >1500 MVA transformers
  - Controllable reactors
  - Low Noise conductors
  - Double circuit technology
  - Plug and play multi-terminal HVDC devices
  - Hybrid HVDC/AC systems

Next Generation Grid Operating System required for grid transformation

The EAC has previously offered recommendations to the DOE that a roadmap be established for the development of a next-generation grid operating system or energy management system

(EMS). The nation's grid faces significant transformation in supply, demand, consumer expectations, and markets. Given the long lead time required to develop and implement fundamental changes in the way the grid is managed, it is imperative to anticipate this transformation. It is envisioned that this EMS system of the future will contain enhanced state estimation and visualization technologies. Development should also include consideration of leveraging evolving high performance computing (HPC), analytics and power system analysis algorithms to take advantage of HPC capabilities.

Lower Cost, Practical Superconducting Cables

New high – temperature superconducting – based transmission cable technology could offer an important alternative to conventional cables in the longer term. These cables use high-temperature superconducting materials instead of copper or aluminum and have substantially higher power handling capabilities than conventional cables. When used for HVDC, these cables exhibit zero electrical losses aside from parasitic refrigeration losses. When used on land, they can be buried in a small width right – of –way. They are currently being demonstrated in small distances.[10]

Expanded Program in Materials for Electric Utility Industry Research

There is an ongoing need for research in innovative technologies both for transmission and distribution applications. This should include things like nanotechnology applications for use in breakers, insulators, conductors and even fluids (for transformers and other devices). It may be argued that these are not Smart Grid technologies, but these material advances promote a smarter responding, more resilient grid. Materials research would include better power electronics devices and new insulating materials that would be a replacement for SF6 or other items facing upcoming pressure, higher efficient materials and more resilient applications.

Distribution

While a small percentage of electricity customers are served directly from the transmission system, the vast majority of the 165 million customers in the U.S. are served by the distribution system, which is comprised of a complex network of substations, lines, poles, metering, billing and related systems to support the retail side of electricity delivery.

Status of technologies ready for adoption

The following technologies have undergone significant research and development and are available for commercial use. As with any technology, advances are continuing in most areas. The adoption of these technologies by the electric utility industry are limited, typically by the business cases that include the costs/benefits analysis each capital investment must undergo before implementation.

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[10] EPRI Program on Technology Innovation: A Superconducting DC Cable, Electric Power Research Institute (EPRI), Palo Alto, CA, 2009

Expand Deployment of Distribution Automation

Distribution automation (DA) involves the integration of SCADA systems, advanced distribution sensors; advanced IED's and advanced two-way communication systems to optimize system performance. In a dense urban network it will also include network transformers and network protectors. The SCADA system collects and reports voltage levels, current demand, MVA, VAR flow, equipment state, operational state, and event logging, among others, allowing operators to remotely control capacitor banks, breakers and voltage regulation. Substation automation, when combined with automated switches, reclosers, and capacitors, will enable full Smart Grid functionality.

This includes not only building intelligence into the distribution substations and into the metering infrastructure but also into the distribution feeder circuits and components that link substations with feeders and the metering infrastructure. This means automating switches on the distribution system to allow automatic reconfiguration, and adapting protection systems to facilitate reconfiguration and integration of DERs integrating power-electronic based controllers and other technologies to improve reliability and system performance, and optimizing system performance through voltage and VAR control to reduce losses, improve power quality and facilitate the integration of renewable resources.

- *Intelligent head-end feeder reclosers and relays:* Replacing electromechanical protection systems with microprocessor-based, intelligent relays and reclosers are an integral part of Smart Grid operation. Advantages include: increased functionality; including both instantaneous and time-overcurrent protection; greater sensitivity; better coordination with other devices; and the ability for self-diagnosis.
- *Intelligent reclosers:* The use of intelligent switching and protection devices on feeders (referred to as "mid-point or tie-reclosers") to allow isolation of segments of feeders to enhance reliability.
- *Remotely controlled switches:* Remotely controlled switches contain distributed intelligence and use peer-to-peer communications to take actions without the need for central control intervention in order to isolate faults and restore power quickly in the event of an outage. As a result, distribution system operators will no longer be the only ones that can perform that function.
- *Power electronics, including distribution short circuit current limiters:* Advances in power electronics allow not only greater fault protection but flexible conversion between different frequencies, phasing, and voltages while still producing a proper AC voltage to the end user.
- *Voltage and VAR control on feeders:* Voltage/VAR controls are a basic requirement for all electric distribution feeders to maintain acceptable voltage at all points along the feeder and to maintain a high power factor. Recent efforts by distribution utilities to improve efficiency, reduce demand, and achieve better asset utilization, have indicated the importance of voltage/VAR control and optimization. Utilities continue to face system losses from reactive load, such as washing machines, air conditioners, and motors. By optimizing voltage/VAR control, greater efficiencies can be realized.

Accelerate Deployment of Advanced Metering Infrastructure (AMI)

An advanced metering infrastructure (AMI) involves two-way communications with smart meters, customer and operational data bases, and various energy management systems. AMI, along with new rate designs and intelligent energy using devices, will provide consumers with the ability to reduce electricity bills by using electricity more efficiently, to provide responsive demand and participate in Demand Response Programs, to select service and pricing options tailored to their preferences, and could help provide system operators and utilities with the ability to operate the electricity system more reliably and efficiently.

Smart meters are the main component of AMI and often have been the first technology deployed by an electric utility in a Smart Grid program. Three basic functions are involved:

- **Smart meters** capable of two-way communication with the utility, remotely programmable firmware, and, optionally, a remotely manageable service disconnect switch. In addition to consumption measurements, smart meter functionality includes: voltage measurement and alarms that can be integrated with distribution automation projects to maximize Conservation Voltage Reduction (CVR) benefits, and interval data to support dynamic pricing, responsive demand, and demand response programs.
- **Communications** system that is highly secure (encrypted), redundant and self-healing, and related hardware and software systems to communicate between smart meters, substation and distribution automation equipment, customer energy management systems, and head-end software applications / meter data management systems.
- **Meter data management system** capable of storing and organizing data, allowing for advanced analysis and processing, and interfacing AMI head-ends with a range of other enterprise software applications.

Advanced Smart inverters

Increasing penetration of DERs, especially solar photovoltaic (PV) systems on the distribution power grid is introducing grid integration challenges for utility engineers. Over voltage, reverse power flow, excessive switching of capacitor banks and/or line tap changers are often experienced in circuits with higher penetration of variable generation sources. Some of these technical challenges can be resolved or at least can be minimized by employing the full potential of power electronics inside the inverters interfacing these sources with the electric grid. Inverters with grid supportive functionality, including reactive power support, low/high voltage ride-through, watt-frequency, watt-voltage, and real power curtailment, can contribute to grid stability and hence assist to increase higher rate of renewable adoption. Closely related to the inverter and control technology is the development of interconnection standards.

Facilitate Conservation Voltage Reduction and Volt-VAR Optimization

Volt/volt ampere reactive (VAR) control is an operating requirement for all electrical distribution utilities. However, in preparing to serve tomorrow’s customer needs, it must now incorporate conservation voltage reduction (CVR) as utilities begin looking for ways to increase the efficiency of the power distribution system, to reduce peak demand, and to conserve energy. In tomorrow's world, not only CVR, but Volt VAR optimization (VVO), will be needed to reduce greenhouse gas emissions, improve system losses, reduce generation requirements, and reduce critical peak impacts to the system. The advanced communications that have been developed by the industry and implemented by the utilities have changed the capabilities of the CVR and VVO systems that are available today[11].

To assure the functionality required by tomorrow's grid, the industry must move from individual voltage or VAR controllers operating independently on the feeders to systems that communicate feeder readings back to a central VVO controller. These central controllers can then calculate optimal operating set points or commands for the system equipment and send them out over the system to create the optimal scenario for CVR and/or VVO on the feeders.

Each utility needs to assess the benefits of CVR and VVO on their system using modeling tools to analyze circuits for CVR/VVO. The effects of implementing various degrees of CVR/VVO on a circuit can be evaluated by using the OpenDSS (Open Distribution System Simulator) modeling tool.

> The Department has supported the development of additional technologies that rely on solid-state power electronics to provide more precise Volt-VAR optimization and greater efficiency. However, these solid-state technologies are in the later stages of development and demonstration.
>
> Additionally, as recommended in the regulatory tools paper adopted by the EAC at its September 2014 meeting, the Department should support the development of analytical tools and information to facilitate the analysis and adoption of Volt-VAR optimization technologies.

Technologies requiring additional research, development, and demonstration

The following described technologies are undergoing significant research and development and in some cases are in very early stages of commercial use.

Computer models for new technologies need to be developed and incorporated into planning tools

While the industry is rapidly expanding its knowledge and experience in planning and operating large HVAC and HVDC systems with increasing levels of DERs, there are several areas where further research and development is needed. Power systems planners use computer models of components to design power systems. As new technologies evolve, there is the opportunity to develop robust data sets on the performance of those technologies under an array of conditions. This data can then be used to develop models for use in accurately modeling the new power system. In the case of many of these new technologies, there isn't sufficient data to develop such models. This hampers the planner's ability to design tomorrow's grids for reliability and availability and to assess the range of configurations available so as to establish optimal designs.

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[11] Grid Strategy 2011: Conservation Voltage Reduction and Volt VAR Optimization in the Smart Grid, EPRI Report 1024482, November, 2011

Develop Alternative Micro-Grid Architectures

Recent storms and the resultant extensive blackouts have raised the question as to what impact would expanding the use of micro- grids have and what would their preferred architectures be so as to enable their functionality and integration into the grid during normal and emergency operation.

Advanced Power Electronics

As mentioned above, increasing penetration of DERs, especially solar photovoltaic (PV) systems on the distribution power grid is introducing newer grid integration challenges for utility engineers. The Department through its ARPA-e program has supported the initial development solid-state power electronics that can be deployed on distribution systems to manage power flows, optimize voltage and reactive power to reduce generation requirements and improve power quality, and in data centers and industrial facilities to ensure power quality and reliability for sensitive applications.

Sophisticated distribution management systems are needed for the next generation grid

A critical gap lies in the capability of the Distribution Management Systems (DMS) used to monitor and control distribution systems. While the state of DMS technology available to electric utilities is evolving from existing components, it is not clear that such an evolutionary development will keep pace with emerging requirements to manage distributed energy technologies.

DMS contain a number of elements. Critical among these is an Outage Management System (OMS). OMS systems are used to manage and restore service to customers following major storms and other events. Reliance on traditional Outage Management Systems (OMS) has become more inefficient as utilities deploy more Supervisory Control and Data Acquisition (SCADA) systems across their distribution grids. Existing systems do not incorporate on the ground conditions in real – time from all relevant data sources. The need for an integrated, real-time distribution management system with computer-aided tools for switching, load flow analysis, fault location and isolation is prompting utilities to move toward advanced DMS. The advanced DMS will support and enable the Smart Grid by becoming the single repository of certain real-time and near-real-time data, as well as, the power system connectivity model (asset characteristics, connectivity, and renderings). Current DMS systems are not tracking net load at the customer level in near-real time; and are not providing an integrated near-real-time model of transmission and distribution power flows; or dispatching or supporting distribution level markets to manage the operation of distributed energy technologies. The DMS in conjunction with the OMS becomes the information foundation to support the Smart Grid including:

- *Faster Simulation and Modeling*: improves situational awareness and decision support.
- *Self-Configuring Grid*: Fault location information, in combination with knowledge of electric connectivity and switch status/remote controllability, will allow the DMS to develop a new configuration to minimize the extent of outages.
- *Condition-Based Maintenance*: Usage and response data inform a condition-based maintenance application to analyze and develop different maintenance strategies.

These strategies can be tested in a study environment within the DMS on the as-operated or as-built model.

Subtle differences exist between DMS products as they have developed from different starting points, either SCADA or OMS, and evolved to their current forms. These different origins have influenced product capabilities. Products derived from SCADA started with schematic one-lines and remain device-centric. These provide switch execution linked to supervisory control systems in native mode and advanced supervisory control device configuration capabilities. These DMS provide real-time architecture for tracking device configurations and managing centrally controlled distribution devices. Alternatively, products developed from OMS remain more customer and outage oriented. This path has provided more experience with distribution processes and provides crew management capabilities in native mode, but their SCADA/tagging capabilities are often somewhat cumbersome. These differences are beginning to blur as DMSs mature and offerings become more comprehensive.

Current DMS offerings serve to integrate certain information and operational systems and to handle the significant quantity of data characterizing the real-time management of the system. A fully functional DMS, given current technology, would consist of a single user interface for SCADA, OMS, distribution system state and switching information, distribution automation applications, and advanced analytics.

Systems that include dynamic transmission and distribution topologies and DERs will require more transparent and integrated planning and more detailed real-time operational management and coordination. The operation of the system in which DERs can impact both distribution and transmission system operations may require:

- A federated control architecture connecting transmission and distribution operations;
- Integrated modeling and state estimation to give both transmission and distribution operators real-time awareness of power flows across transmission and distribution systems;
- A flexible, advanced information architecture to manage a large expansion in operational data, integrate an evolving set of information systems and applications, while maintaining cyber security;
- The ability to commit and dispatch or forecast and coordinate the operation of large numbers of distributed technologies, dynamically manage the topology of mesh or microgrid based distribution networks, optimize voltage, and simultaneously maintain phase balance across the distribution system; and
- Ultimately distribution level market structures that can coordinate settlement of transactions.

These requirements, in part, parallel the types of systems that were developed for the operation of RTOs and ISOs. However, efficient operation of a more highly distributed system will have to accommodate a larger number of control points and manage greater complexity. The extent to which control of such systems should be distributed and how such a distributed control system might operate are open research questions. The development of such systems will require significant, multi-year RD&D investments. And, there is a limited market to support entirely private sector development of such systems. A variety of economic factors and policies will continue to drive the deployment of distributed energy technologies. There could be significant reliability and economic costs if control systems do not advance at pace sufficient to efficiently manage a more distributed energy system. Moreover, if the U.S. were to cede a leadership role in the development of such technologies, this could increase the cyber-security vulnerability of domestic power systems. Therefore, the Department should place a high priority on RD&D for information and control systems to support the efficient integration a more dynamic transmission and distribution grid and larger scale deployment of distributed energy technologies.

Demonstrate and Deploy Power Electronics Enhanced Transformers

Conventional transformers suffer from poor energy conversion efficiency at partial loads, use liquid dielectrics that can result in costly spill cleanups, and provide only one function–stepping voltage. These transformers do not provide real-time voltage regulation or monitoring capabilities, and do not incorporate a communication link. At the same time, they require costly spare inventories for multiple unit ratings, do not allow supply of three-phase power from a single-phase circuit, and are not parts-wise repairable. Future distribution transformers will also need to be an interface point for distributed resources, from storage to plug-in hybrid electric vehicles.

The intelligent universal transformer (IUT) is a first-generation, power-electronic replacement of conventional distribution transformers. EPRI has developed an IUT which can serve as a “Renewable Energy Grid Interface” (REGI). The new concept includes a bi-directional power interface that provides direct integration of photovoltaic systems, storage systems, and electric vehicle charging. It will also incorporate command and control functions for system integration, local management, and islanding.[12] ARPA-E is developing advanced semiconductors that could be used in similar topologies. These developments need to continue and expand to other applications.

Develop Phasor Measurement Units for Distribution Systems

With the increasing number of DERs, many of which are variable and low inertia, PMUs applied at the Distribution System is an area that needs research around the applications and modeling required for real time applications. Micro-PMUs could be used to provide real-time data and visibility for electric distribution participants and systems to use for diagnostic and control applications to support the integration of distributed energy resources. Because of the relatively small angles and high noise-to-signal- ratios on the electric distribution system, the demands on micro-PMU technology design and performance at the distribution level are about an order of magnitude higher than those for transmission. Research and development is underway on micro-PMUs and demonstrations of prototypes are in startup phases at universities and selected utilities in the US. For example, under ARPA-E Award #DE-AR0000340, Micro-Synchrophasors in Distribution Systems, the California Institute for Energy and Environment (CIEE)/University of California Berkeley, in conjunction with Power Standards Lab

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[12] The concept builds on preliminary research and prototypes of a power-electronics based transformer (prototype under development). REGI expands the concept to include a bi-directional power interface and dc bus to support direct integration of photovoltaic systems, storage systems, and electric vehicle charging. The resulting interface would also incorporate the command and control functions with an interface to demand response systems for local loads to allow islanding of the local system.

(PSL) and Lawrence Berkeley National Lab (LBNL), are conducting a three-year research project to develop a high-precision micro-synchrophasor, or µPMU, and to study its applications for diagnostic and control purposes in distribution systems.

Beyond the Customer's Meter

- The customer premise itself is an integral part of the electric power system. The following is a description of areas focused on the customers themselves, or their premises served, that may warrant additional research and development.

Market and Rate Design

Accelerating end-use energy efficiency, increasing consumer adoption of energy generation technologies, the emergence of intelligent energy using devices, and rapid adoption of new technologies such as all forms of distributed energy technologies, including PEVs and energy storage imply a changing business environment. This may necessitate changes in utility rate design, particularly for those customers who choose to take advantage of these new technologies. Rate design changes may also need to accommodate flat or decreasing kWh sales.

Understanding Consumer Behavior

To meet the needs of tomorrow's retail customers served by distributors, it is critical that the industry develop an enhanced understanding of consumer behavior regarding electric technologies. Specifically, the industry needs a comprehensive and accurate evaluation of consumer perspectives toward Smart Grid technologies in order to further the understanding of motivators for consumer adoption. Increasingly, behavioral economics and other social science disciplines are providing insights that can help improve the designs of interfaces between the consumer and Smart Grid technologies. Some smart technologies, including intelligent thermostats, have already been adopted by millions of electric customers often without receiving any utility incentive. In other cases, utilities may seek to test Smart Grid technologies that interface with users and programs approaches aimed at consumers using valid experimental design methodologies prior to providing adoption incentives. Better understanding consumer preference will help coordinate activities ranging from designing informational materials to assisting stakeholders in relating to consumer attitudes in order to improve engagement (EPRI 1024565).

This includes a desire to understand the value drivers in consumer terms and to answer questions such as "How would a consumer experience the technology and benefits of the Smart Grid?" Some intelligent energy using devices will automatically implement customer preferences after purchase of the smart device or its initial online or point-of-purchase program enrollment and require no further engagement with the customer. Other Smart Grid technologies may involve greater consumer engagement. In these cases, utilities must be able to go beyond acceptance and create a "pull" whereby consumers are asking to become involved in Smart Grid technology.

Among the research needs are the following:

- Motivation: What are the key drivers for adoption and ongoing appropriate use of technology which facilitates consumer connectivity to the Smart Grid? This research needs to recognize that consumers are motivated in a broad range of ways and to take advantage of the growing body of behavioral and social science research.

- Understanding: Understanding technology and how to relay this in consumer terms through an understanding of consumer perception, awareness and interest level. Approaches should be tested under experimentally designed pilot conditions.
- Education: Identify keys to effective education and a common industry message to enable the same story to be told, which can promote a consistent level of understanding.
- Incentives and Program Designs: Education alone is often insufficient to motivate consumer action. Consumers are motivated by financial and other incentive or program design aspects such as convenience, trust, competition, social norms, etc. Additional research is needed to refine these areas.
- Competitive Market Development: Given appropriate wholesale pricing and settlements, utilities and competitive retail electric suppliers may package electric supply, intelligent devices, and/or other services in a service offering that helps the customer manage their energy bill. Additional research may help utilities and regulators better understand the market structures and rules that provide economic incentives for suppliers to compete in providing energy services and improve power markets.

PV Inverters

Inverters are microprocessor-based units used to transform DC to AC power that can be used to connect a photovoltaic (PV) system with the public grid. The inverter is the single most sophisticated electronic device used in a PV system, and after the PV module itself, represents the second highest cost. It is also considered the weakest link. Whereas, solar panels are very robust and carry 25-year warranties, inverter warranties have traditionally been in the 5 to 10 year range. Inverter reliability, however, has been trending up.

There are many types of inverters. Some are stand-alone units isolated from the grid and used to support a stand-alone rooftop system; others are grid-tied, in which case the microprocessor circuits are more elaborate and require additional functionality, including lightning protection. Central inverters are used in large applications. Many times they can be connected according to "master-slave" criteria, where the succeeding inverter switches on only when enough solar radiation is available. Module inverters are used in small photovoltaic systems, such as household rooftops.

A new generation of micro-inverters holds promise to increase PV performance. With current PV design, all solar panels are connected in series, so that if any panel in the series is shaded, it brings down the performance of the entire system. Moreover, for a series module to work, all panels have to have the same orientation and tilt, which limits roof top configuration. The micro-inverter scheme, on the other hand, allows each panel to be connected to its own micro-inverter, increasing overall system performance and providing flexibility for the staggered roof designs of many modern homes. Austin Energy, among others, is testing new micro-inverter designs.

Residential Energy Management System (REMS)

A residential Energy Management System (EMS) or REMS is a system dedicated to managing energy usage within a home. There is a broad range of capabilities and architectures for REMS. The REMS can be either passive or active. A passive REMS can present a consumer’s real-time energy usage on an in-home display device. An active system can make adjustments to intelligent home devices IHD, such as smart thermostats, water heaters, etc., based on signals received from the utility or a third party. The REMS can be connected directly to a utility's smart meter and / or connect to the utility or to a third party through the Internet. In addition, the system may handle customer preferences and occupancy via a schedule, on-demand, or occupancy sensing automation. REMS are a subset of a home automation system that can handle lighting, family calendars, shopping or replenishment, and home security. Some recent examples of companies offering REMS devices include NEST Thermostats, Iris system by Lowe's and Nexia system by Trane/Ingersoll-Rand. These companies are focused on providing devices that consumers can procure off-the-shelf and install themselves. Nearly all the off-the-shelf products that are becoming available are using proprietary communication standards and protocols with a "services" business model that locks in customers to only that service provider. As of the writing of this document, preliminary information regarding consumer purchases of advanced residential EMS systems show promise with some systems in millions of homes.

Energy Usage Portal

Most utilities provide their customers with access to their energy consumption data through their website. Many utilities provide this data using a standardized date format called Green Button.[13] Using Green Button allows consumer to make use of third-party apps that analyzes and interprets the data in various ways. These apps can provide consumers with insight into their energy usage and promote energy efficiency. Consumers can, for example, access current energy usage statistics, historical usage patterns, and the amount of carbon dioxide emissions avoided by utilizing a renewable energy source.

These aspects make it difficult to pin the price tag onto the residential EMS. Many components have a dual purpose and exist under separate financial justifications. Consumer reluctance to purchase an EMS may be driven by on-line options that could replace key parts of the functionality of an EMS.

In-Home Displays and Access to Energy Information

Providing real-time feedback on energy consumption holds significant promise to reduce electricity demand. Several studies over the past 30 years have evaluated the effectiveness of energy savings from home energy displays of varying sophistication. Most of these studies verified savings between 5% and 15% with a longer-term sustained impact toward the lower end of this scale.[14,15,16] However, another study found that feedback information in the form of mailed monthly/bimonthly energy reports with neighbor comparisons can results in impacts in

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[13] http://energy.gov/data/green-button

[14] Darby, S. 2006. The Effectiveness of Feedback on Energy Consumption: A Review for DEFRA of the Literature on Metering, Billing and Direct Displays. Environmental Change Institute, University of Oxford. Oxford, UK.

[15] Residential Electricity Use Feedback: A Research Synthesis and Economic Framework. EPRI, Palo Alto, CA: 2009. 1016844.

[16] Ehrhardt-Martinez, K., K. A. Donnelly, and S. Laitner. 2010. Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities. American Council for an Energy-Efficient Economy, June

the 2% range, although there is not enough strong evidence regarding impacts of energy display devices.[17] People need a strong motivation to change, such as competition, recognition by others, compensation, confidence that their actions will make a difference, and feedback that changes they do make are having an impact. In addition this feedback must be easy and trustworthy. As such, most successful approaches provide more frequent feedback, as well as feedback on specific behaviors.

As the Smart Grid unfolds, various methods to provide energy, cost, and environmental information are beginning to emerge. A specific class of stand-alone devices has been utilized extensively and is referred to as the in-home display (IHD). Typically, IHDs present basic information, such as real-time and projected hourly electricity cost and electricity consumption (kWh). Some can display additional information, such as electricity cost and consumption over the last 24 hours, the current month (and/or prior month) consumption and cost, projected usage, monthly peak demand, greenhouse gas emissions, and outdoor temperature. A similar approach is a component of a prepayment system, also known as a pay-as-you-go system, since these also have a display.

Grid-Ready Appliances and Devices

Grid-ready appliances do not require truck rolls to retrofit with remote communications and control capabilities. Grid-ready appliances and devices, which are often referred to as "DR-ready," are manufactured with demand-response (DR) capabilities already built in. The universal entry of grid-ready devices into the marketplace, which is anticipated by some on the EAC to take shape in the next several years, will lead to ubiquitous demand-response capability.

Plug-in Electric Vehicle Charging Infrastructure and On-Vehicle Smart Grid Communications Technologies

Plug-in electric vehicles (PEVs) are defined as any hybrid vehicle with the ability to recharge its batteries from the grid, providing some or all of its driving through electric-only means. Almost all of the major automotive manufacturers have announced demonstration or production programs in the 2010-2014 timeframe, and their announced vehicles feature all-electric, plug-in hybrid-electric and extended-range electric vehicle configurations. Notable and earliest introductions among these are globally targeted production vehicles from General Motors (Chevrolet Volt, extended-range EV) and Nissan (Leaf, battery-only EV).

If integrated with grid operations, flexibility in the timing of charging of EVs can help provide ancillary services, moderate variability in net demand, and manage system and circuit peak demands. These benefits can be realized by impacting whether or not the EV is charging at any specific time without power flowing from the vehicle to the grid.

All applications which may provide reverse flow power capability such as vehicle-to-grid (V2G) are unproven. Their impact on battery durability, utility/automotive/consumer acceptance, and

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[17] Understanding Electric Utility Customers -–Summary Report: What We Know and What We Need to Know. EPRI, Palo Alto, CA: 2012.1025856.

economics are yet to be demonstrated. In addition, it is uncertain what services they will enable and whether policies and incentives will be needed to bring them to reality. V2G, therefore, remains an R&D agenda item of several automotive manufacturers, EPRI, some ISOs/RTOs, and several R&D institutions. It is, however, too early to predict the direction and magnitude of this technology's installed base in the near future.

Communication Upgrades for Building Automation

Today, a substantial number of the conditioned and institutional buildings in the U.S. have some form of energy management and control systems installed. Automated demand response (ADR) can be accomplished by communicating to advanced building energy management systems using an Internet-communicated signal or some other form of direct link. Legacy systems deployed today lack this capability. Open automated demand-response (Open-ADR) involves a machine-to-machine communication standard that provides electronic, Internet-based price and reliability signals linked directly to the end-use control systems or related building and automated control systems[18]. The building automation system is pre-programmed to reduce load according to the messages it receives, and it may also provide real-time energy consumption information back to the utility or service provider.

Employing Open-ADR presumes the building has an advanced EMS system. There are two cost components that enable the building to respond to DR signals. The first is to enable the building's EMS to receive the DR signals. The second and perhaps largest cost component is the programming of load control strategies in the EMS.

Cyber Security

Electric utilities have been incorporating cyber security features into their operations since the early 2000s. In recent years, cyber security concerns have increased significantly. While such concerns are significant without regard for whether a utility has implemented Smart Grid technologies, Smart Grid has helped focus attention on and support the development of cyber security capabilities. Cyber security is an essential element of the Smart Grid. It is the protection needed to ensure the confidentiality and integrity of both legacy utility systems and the digital overlay that is part of the Smart Grid.

This is an area is which there has been a great deal of on-going activity. In fact the EAC has just established a Working Group to review what its role may be and to assess where it can best offer advice. Several recent developments which the EAC's working group is evaluating include: Executive Order 13636 on Cyber Security; the NIST / SGIP Smart Grid Cyber Security Guidelines; the NIST Smart Grid Framework v. 3; cyber recommendations in NIST's 2013 report on Strategic R&D for Smart Grid; DOE's 2013 update to its electric sector risk assessment methodology; and DOE's development of cyber security procurement language for electric delivery systems.

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[18] Automated Demand Response Tests, EPRI Report 1016082, December, 2008

Specifically related to the Smart Grid: The North American Electric Reliability Corporation (NERC) has created eight Critical Infrastructure (CIP) Standards. These include standards for Critical Cyber Asset Identification (CIP002) and Security Management Controls (CIP003) as well as others. At present, utilities are considering cyber security as part of information technology (IT) projects for:

- Advanced metering infrastructure
- Plug-in electric vehicle (PEV) management systems
- Distribution automation
- Substation automation
- Transmission upgrades
- Demand Response Programs
- Communication with DET devices

The United States has embarked on a major transformation of its electric power industry into an advanced, digital infrastructure with two-way capabilities for communicating information, controlling equipment, and distributing energy. This evolution is increasing the dependence on information technology and telecommunications infrastructures to ensure the reliability and security of the electric grid. To realize the full potential of the Smart Grid, cyber security measures must be designed and implemented to protect it from attacks by terrorists and hackers, as well as to strengthen its resilience against natural disasters and inadvertent threats such as equipment failures and user errors. Security must be included in all phases of the system development life cycle, from the design phase through implementation, maintenance, and disposition/sunset (EPRI 1024573).

One of the key requirements to prepare industry for the future is to address cyber security, particularly in the integration framework, reference architecture, and information exchange model. Specifically:

- To develop secure information exchange policy and systems management guidelines, and
- To identify security issues and solutions implemented for communications and information infrastructure to support the integration.

As the Smart Grid drives the evolution of the electric sector, several trends have impacted the role of cyber security:

- Increased connectivity of control systems to other networks, particularly enterprise networks, to obtain productivity improvements and information sharing.
- Widespread deployment of open industry standard protocols that replace vendor-specific proprietary communication protocols.
- Deployment of standardized computer platforms with common operating system to support control system applications.
- Increased reliance on external communications, such as public communication systems and the Internet.
- Increased capabilities of field equipment, for example, “smart” sensors and controls with enhanced capability and functionality.

In the power industry, the historic focus has been on implementation of equipment that could improve power system reliability and quality. Communications and information technology (IT) equipment were seen typically as supporting power system reliability. The various departments, particularly the IT and grid operations organizations, often worked in silos – with limited coordination and with different cyber security requirements.

As the Smart Grid evolves, the electric, communications, and IT sectors are converging to support power system reliability and privacy of consumer information. From a practical perspective, this means the integration of corporate IT systems, legacy components and devices (with limited or no cyber security), and grid operations systems into the Smart Grid. When all these systems are integrated into the Smart Grid, cyber security mitigation strategies must be developed to address the security weaknesses. Cyber security in the Smart Grid must include a balance of both power and cyber system technologies and processes in IT and power system operations and governance.

A great deal of research is needed to enhance IT technologies to enable them to withstand attacks and intrusions.

Communications

Nearly all of the technologies above will generate new data that will be available for use. Hence, new infrastructure capable of supporting the higher level of information monitoring, analysis, and control required for Smart Grid operations, as well as the communication infrastructure to support full integration of upstream and downstream operations, will be needed. At the same time, it is necessary to ensure the privacy and security of individual customer information.

For example, the substation of the future will require a wide-area network interface to receive and respond to data from an extensive array of transmission line sensors, dynamic-thermal circuit ratings, and strategically placed phasor measurement units. The smart substation must be able to integrate variable power flows from renewable energy systems in real time, and maintain a historical record or have access to a historical record of equipment performance. Combined with real-time monitoring of equipment, the smart substation will facilitate reliability-centered and predictive maintenance.

The core and distributed IT infrastructure will be able to coordinate the flow of intelligence from critical equipment, such as self-diagnosing transformers, with downstream operations, and be able to differentiate normal faults from security breaches. It will be able to distill and convey critical performance data and maintenance issues to back office systems.

The smart substation will build upon the existing platform. There is already a significant installed base of sensors at substations, but there is still limited bandwidth connecting the substation to the enterprise. Historically, the communications channel to the substation was justified as part of the installation of the energy management system (EMS) and supervisory control and data acquisition (SCADA) systems. A key consideration for the future is that these legacy systems have limited bandwidth.

Communications constitute the critical backbone for integrating customer demand with utility operations. Detailed, real-time information is key to effectively managing a system as large and dynamic as the distribution power grid. Each smart meter in the advanced metering infrastructure (AMI) must be able to communicate with a wide range of user control systems, as well as reliably and securely communicating performance data, price signals, and customer information to and from an electric utility's back-haul system.

No single technology is optimal for all applications. Among the communications media now being used for AMI applications are cellular networks, licensed and unlicensed radio, and power line communications. In addition to the media, the type of network is also an important part of communications design. Networks used for Smart Grid applications include fixed wireless, mesh networks, and a combination of the two. Several other network configurations, including Wi-Fi and Internet networks are also under investigation.

Interoperability remains one of the most critical success factors for Smart Grid communications. There is growing interest in the potential use of the Internet Protocol Suite (TCP/IP) as a networking protocol that could run over many different communication technologies. In June, 2009, EPRI submitted a *Report to NIST on the Smart Grid Interoperability Standards Roadmap* that became the starting point for NIST's own roadmap, released in September, 2009 (www.nist.gov/smartgrid). In 2014, NIST published Release 3.0 of the NIST Framework and Roadmap for Smart Grid Interoperability Standards, reflecting its collaboration with the Smart Grid Interoperability Panel and the work and input of hundreds of technical professionals.

Conclusion

The increasingly affordable solar, micro – CHP (combined heat and power), Plug – In – Electric Vehicles, storage, micro-grid, and potentially small wind generation units are empowering consumers. The disruptive nature of the multitude of customer demands, technological capabilities, and the potentially deleterious impact on utility revenues concerns utility company executives, regulators, and other policy-makers. How to manage the pace of change within an affordable rate structure is of concern to all of the above, plus customers.

The DOE most important and fundamental role is to accelerate research, development, and demonstration of beneficial new energy technologies that might otherwise not go forward in the absence of this assistance. DOE can also verify the effectiveness and reliability of new technologies; demonstrate the effectiveness of such technologies through demonstration/pilot projects; and promote utility and regulatory awareness of the benefits of such technologies that deliver value to customers and meet customer expectations for cyber-security, resilience, reliability and other needs. The DOE also has a role in helping facilitate the development and deployment of innovative technologies by collaborating with the private financial sectors to develop the instruments that minimize risk to the ultimate electric customer

DOE also plays an important functions when it helps utilities and regulators understand the disruptive nature of technological change combined with increasing customer demands/opportunities; help utilities and regulators develop evolutionary business/regulatory models to accommodate these changes in ways that encourage utilities to develop new or different ways to serve their customers and regulators to develop new models that permit customers to choose their own path, while still meeting shareholder expectations.

The DOE should convene interactive sessions involving utility executives, regulatory leaders, consumers, other policy-making leaders, technological innovators/researchers, national lab staff, and financial community leaders and discuss the disruptive changes that are and will occur. The

Department should allow the proverbial marketplace work out which options are correct for each utility/regulator/customer, but engage the relevant sectors in discussions about options, paths and collaborative programs.

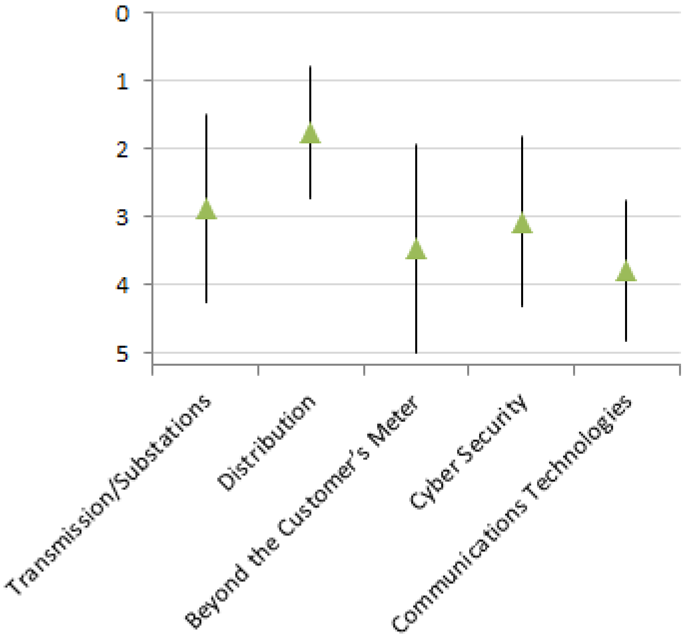
Appendix: Results of DOE Electricity Advisory Committee Survey on Smart Grid Research and Development

In January 2015, the EAC surveyed its own membership on the topic of federal funding priorities for energy R&D. The survey was intended to gain insights on the Committee's views regarding Research and Development needs relative to the Smart Grid. The full text of each question is presented below together with a summary of the results.

The mean value of the twenty five responses from the Electricity Advisory Committee is shown below. The figures show the mean value for each option as a data point with symmetric error bars showing one sample based standard deviation above and below the mean.

Question One: What should be the highest priority categories for research supported by the DOE Office of Electricity Delivery and Energy Reliability? Please rate the importance of DOE being active in each of these in order or priority (1 to 5.)

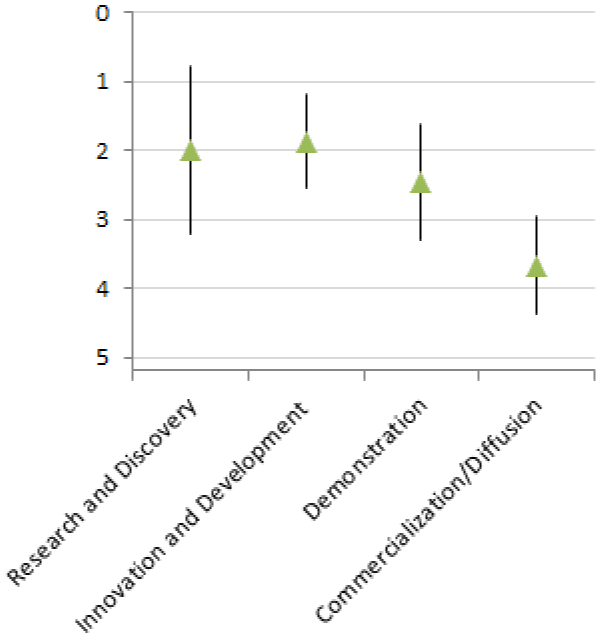
- Transmission Lines and Substations
- Distribution
- Beyond the Customer's Meter
- Cyber Security
- Communications Technologies



Question Two: The maturity of Electricity technologies can be thought of as progressing through four stages from birth to wide- spread adoption. These can most easily be described as:

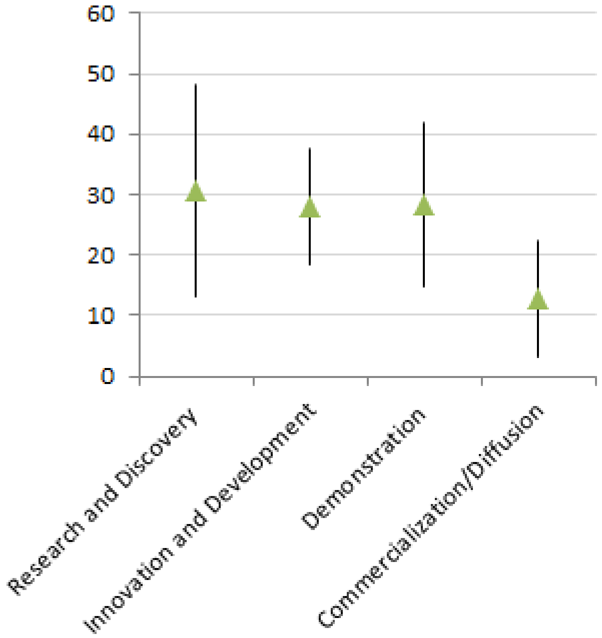
- Research and Discovery
- Innovation and Development
- Demonstration
- Commercialization and Diffusion

Please rate the importance of DOE being active in each of these in order or priority (1 to 4.)



Question Three: What percentage of DOE's budget in the Office of Electricity Delivery and Energy Reliability would you allocate among those four stages (should total 100).

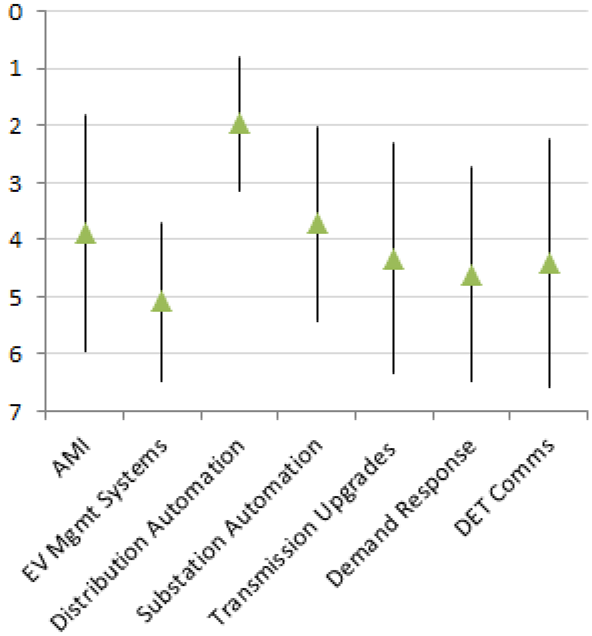
- Research and Discovery
- Innovation and Development
- Demonstration
- Commercialization and Diffusion



Question Four: Which of the following applications related to the smart grid deserve the highest priority in DOE's R&D program?

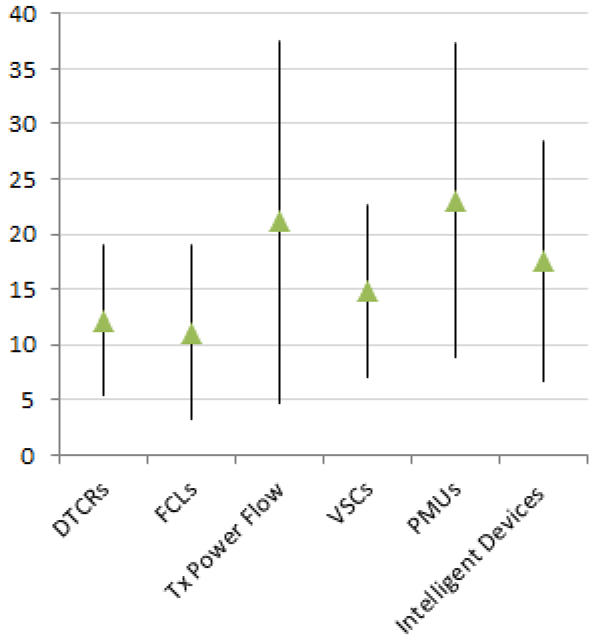
- Advanced Metering Infrastructure
- Electric Vehicle Management Systems
- Distribution Automation
- Substation Automation
- Transmission Upgrades
- Demand Response Programs
- Communications with DET Devices.

Please rate the importance of DOE being active in each of these in order or priority (1 to 7.)



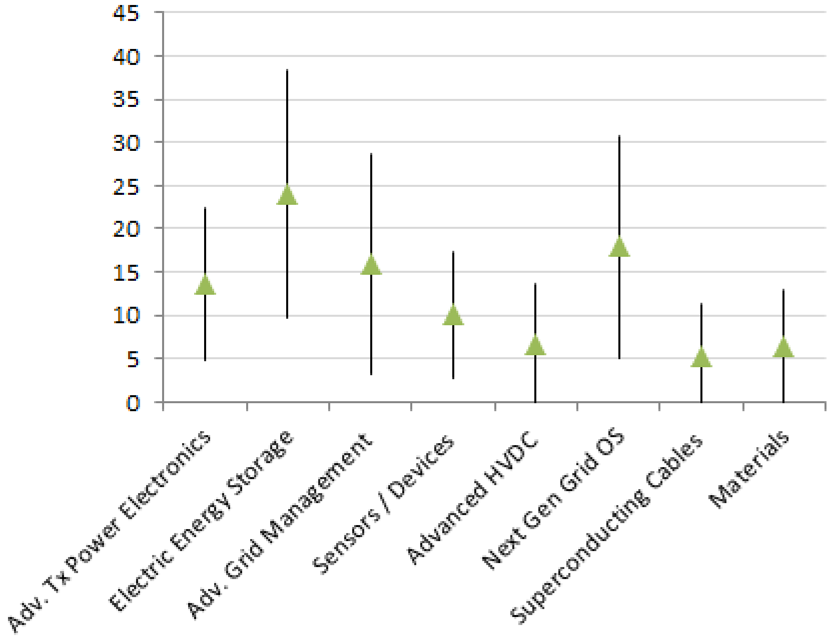
Question Five: In the category of Transmission Lines and Substations there are a number of smart grid technologies listed as available now. What percentage of the budget potentially available to this area would you allocate to each of the following (should total 100)?

- Dynamic Thermal Circuit Rating (DTCRs)
- Fault Current Limiters (FCLs)
- Transmission Line Power Flow Technologies
- Voltage Source Converters
- Phasor Measurement Unit Systems
- Intelligent Electronic Devices



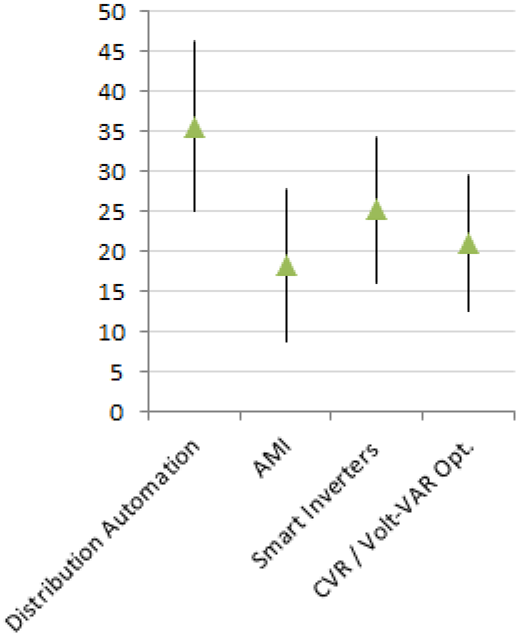
Question Six: In the category of Transmission Lines and Substations there are a number of technologies related to the smart grid listed as still in R&D. What percentage of the budget potentially available to this area would you allocate to each of the following (should total 100)?

- Advanced Power Electronics for Transmission Applications
- Electric Energy Storage
- Transmission Operations – Advanced Grid Management Tools
- Sensors and Other Intelligent Electronic Devices
- Advanced HVDC Technologies
- Next Generation Grid Operating System
- Superconducting Cables
- Materials for Electric Utility Industry Research



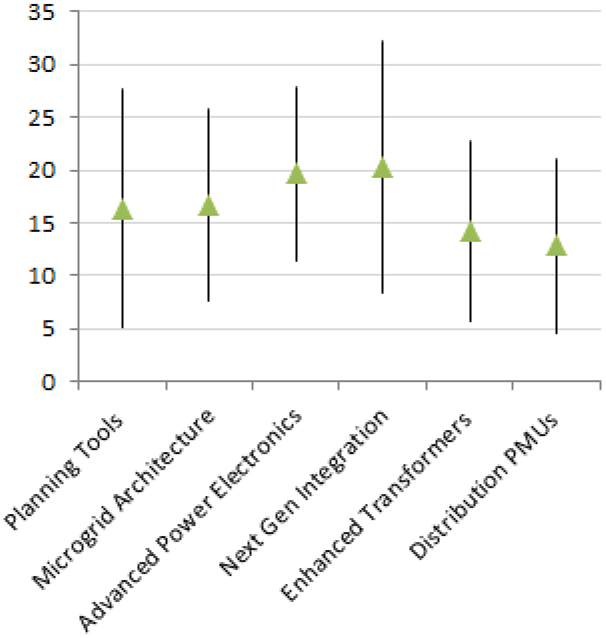
Question Seven: In the category of Distribution there are a number of technologies related to the smart grid listed as available now. What percentage of the budget potentially available to this area would you allocate to each of the following (should total 100)?

- Distribution Automation
- Advanced Metering Infrastructure
- Smart Inverters
- Conservation Voltage Reduction and Volt – VAR Optimization



Question Eight: In the category of Distribution there are a number of technologies related to the smart grid listed as still in R&D. What percentage of the budget potentially available to this area would you allocate to each of the following (should total 100)?

- Planning Tools
- Micro-Grid Architecture
- Advanced Power Electronics
- Next Generation Integration
- Power Electronics Enhanced Transformers
- Phasor Measurement Unit Systems for Distribution Systems



Question Nine: In the category of Beyond the Customer's Meter there are a number of technologies listed that are related to the smart grid. What percentage of the budget potentially available to this area would you allocate to each of the following (should total 100)?

- Market and Rate Design
- Understanding Consumer Behavior
- PV Inverters
- Residential Energy Management Systems
- Energy Usage Portal
- In-Home Displays and Access to Energy Information
- Grid – Ready Appliances and Devices
- Plug-In Electric Vehicle Charging Infrastructure and On-Vehicle Smart Grid Communications Technologies
- Communications Upgrades for Building Automation