Electricity Advisory Committee

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:	**September 25, 2014**
RE:	**Expanding and Modernizing the Electric Power Delivery System for the 21st Century**

Introduction

The United States electricity system is undergoing more change than it has in many decades. The causes are numerous: a changing mix of resources driven by lowering prices, climate change and policy considerations; the changing role of utility customers on the distribution grid from simple consumers to both consumers and generators of power; a large and rapid increase of remotely located variable renewable generation and the rise of unconventional gas resources, which is putting pressure on baseload conventional power sources like coal and nuclear energy; concerns over reliability and cyber-attacks; and the need to contain costs as future needs are identified and met in a timely way, to name some of the most important.

This rapid change is also being fed by rapid innovation and deployment of advanced power electronics, technologies that rely on high speed communication, controllable energy efficiency and dispatchable demand response programs, markets, and policies; as well as new market entrants, information technology and electricity storage that is increasing the speed of system scheduling and dispatch. Costly and destructive extreme weather events, such as Superstorm Sandy, have underscored the urgency to bolster the system and improve resiliency, i.e. the ability to quickly restore service after storm-related or other outages occur. Regulators and both transmission and distribution system operators are placing a premium on consolidating and better coordinating control areas and enhancing situational awareness, both to enhance reliability and address system vulnerabilities. The same changes that make the system more flexible and easily operated, make integrating growing amounts of variable renewable energy resources easier and less expensive.

Speed, efficiency, and enhanced coordination and control are some of the most important characteristics defining the 21st century power delivery system, referred to in this paper as the grid. Flexibility, reliability, resiliency and security are the system's most critical needs.

This paper will examine: the factors influencing the shift; the needs and expectations of tomorrow's evolving consumers the expanded and modernized grid will serve; the operational improvements needed to facilitate the 21st century system; and suggest ways the Department of Energy can use its resources, research and development capabilities, and market development and commercialization tools to facilitate the grid improvements the nation needs while keeping the costs to citizens, businesses and industries affordable. Specific technology R&D needs will be outlined in a companion paper.

The change is underway. Meeting the nation's future electricity needs in an orderly, responsible and cost effective manner is the challenge.

Factors Influencing Changes in the Grid

The threat of climate change, State and federal energy and environmental regulations, increasing central station renewable and distributed energy resource penetration and the advent of shale gas have fueled a transformational shift for the electric grid. The United States has only begun to conceive the changes to the grid that are needed to ensure our nation's electricity future.

Evolution of the electrical grid

The current configuration of the bulk transmission system developed since the 1950s to present around the location and distribution of both generation resources and demand centers. In fact, the eastern grid was formally integrated in 1962 with the interconnection of three independent grids. The most significant amount of growth in transmission occurred in the 1980-1990 period as large central station generating facilities were constructed to take advantage of their scale, meet growing demand, as well as to efficiently increase reliability through the exchange of energy during normal and emergency operations (See Figure 1 below).

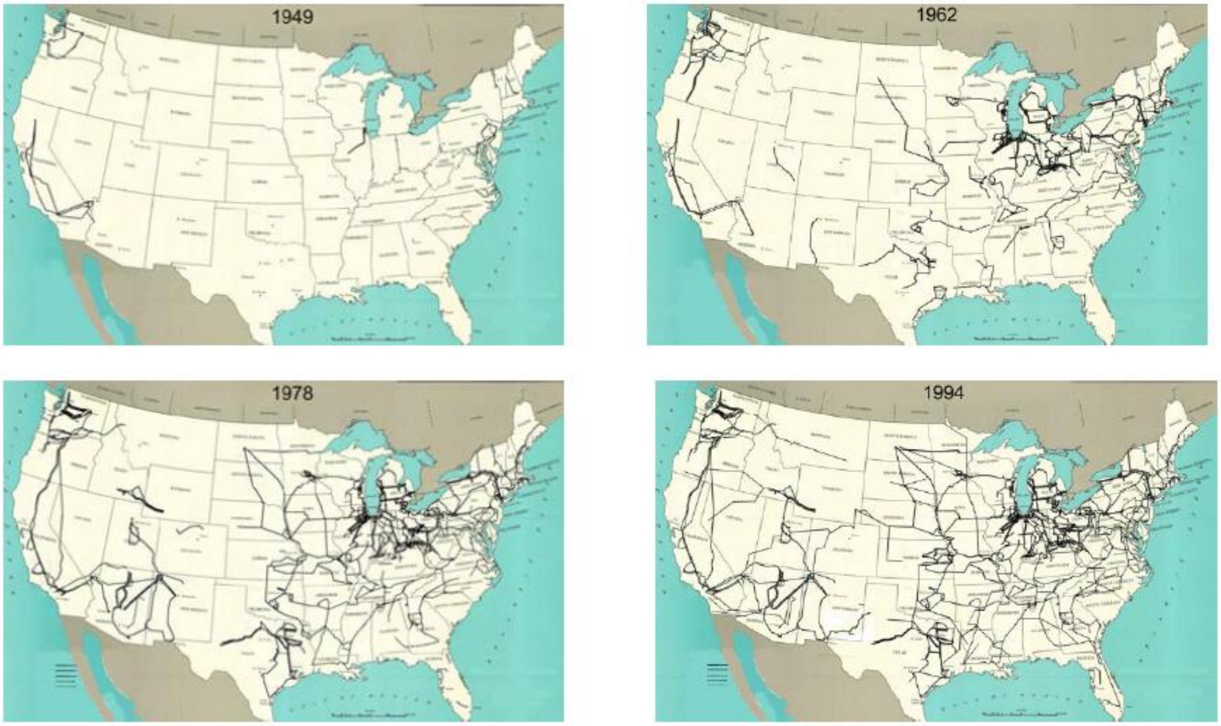

Figure 1: Evolution of the US Bulk Electric System

The transformation of the architecture of the grid began in the 20th century to enable previously isolated networks to take advantage of the economies of scale of interconnection, improve reliability, and share both resources and the diversity of demand. Electricity prices dropped with technology integration and interconnection.

Then demand slowed as the economy matured and prices rose. Demand-side management, PURPA (1978), restructuring and market development attempted to stem the tide of rising prices. Investment in the transmission and distribution grid slowed due to lower demand growth (and efficiencies) and the confusion (from an investor's standpoint) in the transmission space with the advent of organized markets, along with independent system operators (ISOs) and regional transmission operators (RTOs).

Investments in the transmission grid increased substantially soon after the Energy Policy Act of 2005 (EPAct 2005) and FERC's actions in response,[1] coupled with more robust regional planning. The blackout of 2003 in the Northeast, the precursor of EPAct 2005, was a rude awakening for the need to ensure reliability with mandatory standards. Investments essentially doubled per annum in transmission

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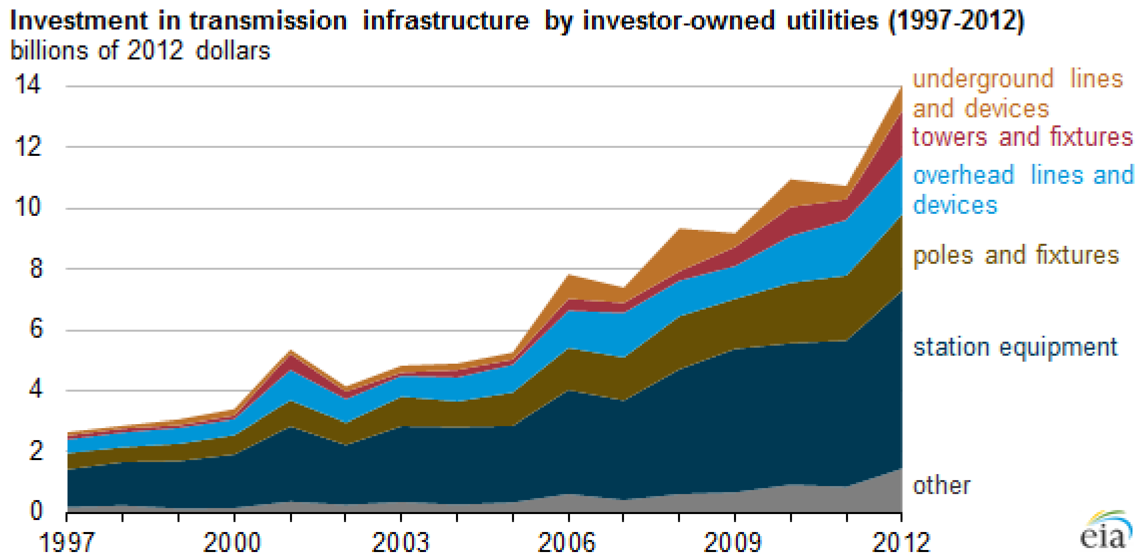
[1] Section 1241 of EPAct 2005 directed FERC to provide incentive rate treatments to encourage transmission infrastructure investment. Energy Policy Act of 2005, Pub. L. No. 109-58, 119 Stat. 594, 315 and 1283 (2005).

between the 1990s and early 2000s. Recent transmission investments have also spiked to address the energy changes and shifts in generation mix that are occurring in the United States.[2]



Restructuring in some portions of the country supported by organized electricity markets created a horizontal unbundling of the grid by separating electricity supply from end use, interconnected by transmission and distribution (wires). Retail providers emerged to create demand response products to enable end-use customers participate in the market place. Other portions of the country remain in a vertically integrated paradigm from supply to end-use. Price in some portions of the country has been a primary driver of restructuring, with lower price areas of the country remaining with the status quo to preserve their price position. As variable renewable generation has begun to assume larger and larger market share, vertically integrated parts of the country are exploring new market coordination strategies to more efficiently and reliably integrate these low-carbon resources.[3][4][5] These range from increased market coordination efforts in the Northwest Power Pool and enhanced control measures, to an Energy Imbalance Market between California and PacifiCorp covering much of the Western

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[2] There has been a five-fold increase in new electricity transmission investment in the United States by major investors and privately owned companies during the 15 years from 1997 to 2012. The investment increased from $2.7 billion in 1997 to $14.1 billion in 2012—reversing a three-decade decline. See: http://www.eia.gov/todayinenergy/detail.cfm?id=17711

[3] October, 2014 the California Independent System operator and PacifiCorp launched the first regional Energy Imbalance Market in the WECC footprint. For more see; http://www.caiso.com/informed/pages/stakeholderprocesses/energyimbalancemarket.aspx

[4] The 22 members of the Northwest Power Pool are developing a security constrained economic dispatch initiative to enhance grid coordination and operations. See: http://www.nwpp.org/our-resources/MC-Initiative

[5] SPP formed a Regional Transmission Organization running an Integrated Marketplace on March 1, 2014. The Integrated Marketplace and its Day-Ahead Market, Real-Time Balancing Market, and Congestion Hedging Markets are expected to yield up to $100 million in annual net benefits to SPP's RTO region see: http://www.spp.org/publications/SPP%20Fast%20Facts%2006052014.pdf.

Interconnection, and a new real time energy market in the Southwest Power Pool RTO. More coordinated operational strategies have emerged as a means to control system costs and boost system efficiency and use.

Toward a "Smart Grid"

The term "Smart Grid" was created to describe a grid that incorporates more automation, supports customer interaction, and ultimately customer choices about energy use and supply. The smart grid is much more than just advanced customer meters. It is an architecture that enables markets and customers to improve the efficient use of the grid, with a two-way communications network working in parallel with the traditional wires.

As new transmission and distribution technologies, such as smart grids and micro-grids, along with new forms of resources, such as variable renewable generation, micro-generators, demand-side management and storage become available; the transmission system will need to evolve to support their integration. Ultimately, the power system will consist of a hybrid; transmission and distribution technologies, supporting both transmission-connected and distribution-connected resources. The architecture of the grid will continue to evolve over time, as new technologies emerge, some brought forward by new market entrants, and as policy makers express societal preferences through legislation, regulation and economic incentives.

Converting the world's largest economy from a high carbon to a low-carbon emitting system will require decades of work, substantial investments both in supply and grids, and consideration of a large amount of affordable zero-carbon options, including energy efficiency, demand response, nuclear generation and renewable energy resources. In addition, as the carbon content of the integrated grid continues to decline (especially if IPCC targets of an 80% reduction in greenhouse gases is to be attained by mid-century), it will become increasingly desirable to electrify more end-use application of fossil fuels. Plug – in electric vehicles are a current example of this opportunity.

Justifying the need for transmission to regulators and the public is not an easy task, but it can be done more easily now and in the future, as the Bonneville Power Administration (BPA) showed in the 2000s by aggressively pursuing energy efficiency and demand response programs *before* turning to new transmission[6]. By making real gains in these areas, BPA was able to reduce the amount of new infrastructure it needed and make the public case for modernization and expansion of its system. They encountered less public opposition to transmission they truly needed. This was a valuable lesson and extremely relevant today. Indeed, this approach is included as part of the Federal Energy Regulatory Commission's Order 1000 transmission planning rule, which among other things requires transmission planners to consider non-wires alternatives to meeting system energy and grid reliability needs.[7] Having

[6] Bonneville's philosophy for non-wires alternatives analysis can be found at http://www.bpa.gov/Projects/Initiatives/Pages/Non-Wires.aspx

[7] For an in-depth look at the rule and its justification see: http://www.ferc.gov/industries/electric/indus-act/trans-plan.asp

a justification for building the lines which considers and implements appropriate options is one way to more easily identify beneficiaries and allocate costs fairly. This in turn could ease approval and cost recovery by state and local permitting and state utility regulatory authorities.

What does the 21st Century Consumer want?

The most obvious desires of today's electricity consumers are the same as they have always been: reliable service at a reasonable cost. For all classes of consumers, from residential apartment dwellers to the Nation's largest industries, the ability to flick the switch and have the lights go on, and the receipt of a reasonable bill at the end of the month, are of paramount importance. These priorities are not likely to change, and therefore no matter what transformation the Nation's electric infrastructure undergoes, it must meet these fundamental expectations of the electricity consumer.

At the same time, the expectations of many have expanded and are likely to expand even further in the future. For example, in recent years the demand for greater levels of reliability has increased, particularly for customer premises where an even momentary lapse in electric service can have significant negative impacts. In addition, in some areas there are customers who no longer only receive power from their utility, but also produce their own power, or even sell it back to the grid, through distributed energy resources on the customer side of the meter. Though this has been ongoing for decades, tax credits, incentives and regulatory mandates are expected to increase the need to integrate distributed as well as centralized generating technologies. Utilities are therefore being asked to be both more resilient and flexible in meeting the needs of the 21st century consumer.

The reliability of the electrical system is arguably the single most important factor in maintaining a healthy economy. As more variable, renewable energy comes on to the system, the 21st century electric reliability requirements will demand a higher level of operational coordination, situational awareness, communications, and more effective automated information and controls. These improvements, which enable system operators to dispatch resources more efficiently and accommodate energy from a variety of different sources with multiple operational characteristics, ensure that sufficient essential reliability services are available, and better use transmission assets, are anticipated to be beneficial to both the least cost integration of variable energy resources and maintain overall system reliability.[8][9][10][11] The more flexible, coordinated and efficient the grid is, the more reliable it will be for consumers. The depth and

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[8] Schwartz, Lisa, Porter, Kevin, Mudd, Christina, Fink, Sari, Rogers, Jennifer, Bird, Lori, Hogan, Mike, Lamont, Dave and Kirby, Brendan (June 2012). "Meeting Renewable Energy Targets in the West at Least Cost: The Integration Challenge," WGA, http://www.westgov.org/initiatives/rtep

[9] National Renewable Energy Laboratory (2012). "Renewable Electricity Futures Study." Hand, M.M.; Baldwin, S.; DeMeo, E.; Reilly, J.M.; Mai, T.; Arent, D.; Porro, G.; Meshek M.; Sandor, D. eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gove/analysis/re_futures/

[10] See also: Western Electricity Coordinating Council, September 8 Event Recommendations, June 30, 2014,Monthly Progress Dashboardhttp://www.wecc.biz/About/sept8/Documents/Progress%20Dashboard%20June%202014.pdf

[11] Carl Linvill, Janine Migden-Ostrander, Mike Hogan, "Clean Energy Keeps the Lights On," Regulatory Assistance Project, June 2014

level of flexibility required is an essential area of research and required industry coordination across interconnections.

In deciding what the 21st century consumer wants, it is important to differentiate among customer classes and even among customers within a particular class. For many residential consumers, the only time they think about their electric utility service is when they pay their bill or when they suffer a service outage. For these consumers, it is essential that the utility of the future (much like the utility of the past) continue to provide a basic reliable "default" service that does not take up an excessive portion of the customer's household income. This is especially important for low-income consumers who, according to a 2010 Oak Ridge National Laboratory study, spend about 10% of their monthly income on home energy bills;[12] however, another study finds that price and affordability are key elements in decision-making about energy for all consumers, not just low-income.[13] The cost of electricity is, of course, also of vital concern to America's commercial and industrial customers, who must remain competitive on both a national and international basis, and for whom, in the case of some energy-intensive industries, the cost of energy can be one of if not the single greatest cost of doing business.[14]

Even if electric service is reasonably priced, however, that is of limited benefit to customers if that service is not reliable. A number of recent studies have illustrated the public's interest in maintaining or improving the reliability of the electric network. A 2013 analysis performed for NARUC and the Maryland Public Service Commission addresses "the tremendous costs, inconveniences, and other effects of outages to customers during catastrophic events."[15] For residential customers, these costs may range from a refrigerator full of spoiled food to the need to maintain essential health care devices or find alternative shelter in the event of an extended outage. With respect to certain types of business customers, the NARUC/MDPSC study cites the conclusion of an earlier EPRI Report "that an outage of any length, even one-second, creates a substantial loss."[16] As noted in the EPRI Report, this is particularly true for businesses such as data storage and processing facilities as well as manufacturers that continuously feed raw materials at high temperatures through an industrial process. Recent weather-related electricity outages of historic proportions, such as those arising from Superstorm Sandy and Hurricane Irene, have brought the issue of the reliability and resiliency of the Nation's electric network to the fore in the minds of policy-makers and the general public. It is therefore not surprising that a recent survey of electricity consumers found that a large percentage of customers (41% of those

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[12] Oak Ridge National Laboratory, Weatherization Assistance Program Technical Memorandum, http://weatherization.ornl.gov/pdfs/ORNL_TM-2010-66.pdf, March 2010, page 5

[13] http://www.accenture.com/SiteCollectionDocuments/PDF/Understanding_Consumer_Preferences_Energy_Efficiency_10-0229_Mar_11.pdf

[14] See, EIA International Energy Outlook 2013, Industrial Sector Energy consumption, http://www.eia.gov/forecasts/ieo/industrial.cfm

[15] Cost-Benefit Analysis of Various Electric Reliability Improvement Projects from the End-Users' Perspective (2013) at page 10,http://www.naruc.org/Publications/FINAL%20MD%20SERCAT%202013_for%20posting.pdf

[16] Id. at 36-37., citing EPRI, "The Cost of Power Disturbances to Industrial and Digital Economy Companies" (June 2001)

living east of the Mississippi and 34% of those living west of the Mississippi) said that they would be willing to pay an additional $10 per month in order to ensure a more reliable grid.[17]

At least according to some analysts, however, providing reliable service at a reasonable price is not enough for the 21st Century utility. As stated in a 2013 Accenture report on the "New Energy Consumer":

> Utilities have largely delivered on the core purpose of the energy value chain: to provide safe, reliable, low-cost energy. While that purpose remains important, achieving it is no longer enough to drive success. Around the world, utilities are facing fundamental changes. Energy consumers' expectations are increasing, technological advances are creating exponential step-change, and regulatory and market forces are fueling complex, sometimes contradictory, priorities for providers. In short, marketplaces are transforming and creating new strategic challenges and operational pressures that cannot be ignored.[18]

In addition to expecting reliable service at reasonable cost, some consumers are now looking to their utilities for new and different types of services. These consumers want to take a much more active role in determining where their energy comes from and how it is provided. As noted above, one of the most dramatic changes in consumers' relationships with their utilities can be found where distributed energy resources such as solar photovoltaics have proliferated on the customer side of the meter. No longer do these households just buy power from utility companies; they make it themselves, and the distribution grid that was once a dropping off point for electricity from power companies is the focus of a transactional relationship between electricity customers and the utility companies. This fundamental shift along with other factors such as declining utility load growth is prompting a reconsideration of utility business models in a few jurisdictions across the U.S.[19]

One state in which the changing relationship between the utility and consumer is the focus of regulatory scrutiny is California. The importance of customer participation to meeting the state's energy goals was clearly set forth in a 2013 Report issued by the Staff of the California Public Utility Commission[20]. As stated in that Report:

> Customers are not only the key to our energy efficiency goals, but also to our renewable, smart grid, and transportation electrification goals. This elevation of the customer roles is a paradigm shift from the historical view of utility consumers as merely

[17] GE Digital Energy Grid Resiliency Survey (August 14, 2014), http://www.gedigitalenergy.com/gegridsurvey/#consumerExp

[18] http://nstore.accenture.com/acn_com/PDF/Accenture-New-Energy-Consumer-Handbook-2013.pdf at 8.

[19] "Utility and Regulatory Models for the Modern Era", America's Power Plan, Ronald Lehr, The Electricity Journal, Volume 26, Issue 8, October 2013, Pages 35–53

[20] http://www.cpuc.ca.gov/NR/rdonlyres/A0A816A2-9F1C-4F34-90DB-C23551F09738/0/PPDCustomerRoleMay15th.pdf http://www.cpuc.ca.gov/NR/rdonlyres/A0A816A2-9F1C-4F34-90DB-C23551F09738/0/PPDCustomerRoleMay15th.pdf 2013: at pages 5-6.

> ratepayers and passive recipients of electricity service to active participants in the power grid. In fact, this energy future represents a fundamental change in the relationship between the utility and the customer, increasing the onus on both to become partners.

The New York Public Service Commission has also been at the forefront of addressing the changing relationship between that state's utilities and its consumers. In its April 25, 2014, Order issuing the Commission Staff Report entitled "Reforming the Energy Vision," the NYPSC requests comment, inter alia, on "a new business model for energy service providers in which distributed energy resources (DER) become a primary tool in the planning and operation of electricity systems, and in which customers are empowered to optimize their priorities with respect to reliability, cost, and sustainability."[21]

Inherent in both inquiries is a fundamental question, as yet unanswered, as to whether utility consumers really desire or expect to become "active participants in the power grid." Indeed, the NYPSC Staff Report recognizes that not all consumers are interested in or equipped to participate in the active role enabled by these new technologies. In a section entitled "Maintain Commitment to Affordable Universal Service," the Report states:

> Reliable utility service will continue to be available to all customers at the lowest cost achievable. The distributed grid should be developed in a manner that does not introduce cost shifts from self-generating customers to non-self-generating customers. Rate design changes must ensure that the burden of providing the utility's revenue requirement do not fall disproportionately on those customers who lack the opportunity to install distributed energy resources (DER) or otherwise participate in DSPP markets. Rental and low income customers, for example, are less likely to invest in or own DER. For those customers that do not have or desire to have DER behind the meter, default service must continue to be available on reasonable terms. The definition of default service will need careful examination and development in this proceeding with the understanding that participation in DER must be by consent, not imposed on customers.[22]

The system benefits obtained through the private investment of customers whose self-generation may postpone or altogether avoid power plant and transmission investments must also be taken into account in determining what is fair and equitable.

As illustrated by the NYPSC Report noted above, there is not one, but many varied sets of expectations that 21st Century consumers will bring to the electric grid. This was also recognized in a 2013

[21] Case 14-M-0101 - Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision. Order Instituting Proceeding, NYPSC Order at 4 (April 25, 2014)

[22] Case 14-M-0101: Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision, Staff Report at 58-59.

Department of Energy report on consumer engagement in smart grid developments which concluded that: "One size does not fit all."[23] As noted in that report:

> Communities, operating structures, and environments vary and what works for one utility may not work for another. For example, an approach to engaging customers that works or is needed for a large urban utility, may not work – and could even be problematic – for a rural cooperative. Likewise, variations in the technology may require different approaches to engaging the community and customers.[24]

Of course, the affordability and reliability of the grid was enabled, in part, by this "one size fit all" approach, especially as electrification of the Nation enabled the growth and societal benefits. However, with the advent of new technologies, a new model is emerging which can accommodate many energy resources, with a variety of characteristics towards a more customized electric service.

One concern that should be noted in connection with consumer engagement with technological innovations is increased consumer concern about data privacy. A recent report on best practices for smart meter data spotlighted instances of consumer resistance to smart meter or advanced metering infrastructure deployment, noting that:

> Since smart meters measure customer electricity usage in far more granular time increments than standard meters, some customers perceive that utilities will know more intimate information about their electricity usage. Rightly or wrongly, some customers are uncomfortable with utilities or any other outside party possessing such fine levels of information.[25]

In sum, in order to meet the expectations of the 21st Century consumer, the electric industry must continue to meet its long-standing goals of providing reliable service at a reasonable cost to all consumers, while also developing the flexibility and responsiveness required to integrate complex supply options to serve the evolving needs of a growing set of consumers who seek new and more advanced ways to meet their electricity needs.

Transmission

Throughout the integration and evolution in the architecture of the grid, transmission will continue to be a vital link to provide a highly reliable system that transports resources to demand centers, manage resource risks, as well as provide essential reliability services to support technology innovation and resource integration and operation.

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[23] DOE, Voices of Experience, Insights on Smart Grid Customer Engagement, at 5, https://www.smartgrid.gov/sites/default/files/VoicesofExperience_Brochure_9.26.2013.pdf

[24] Id.

[25] American Public Power Association, "Smart Grid Data Privacy Concerns: An Overview of Recommended Guidelines," August 2014; http://publicpower.org/Topics/landing.cfm?ItemNumber=38513&navItemNumber=37547

For example, the integration of the new generation technologies into the bulk power system and the ability to move power long distances will be crucial for maximizing the penetration of variable renewable resources into the electrical system over the coming 30 years. Over time, policy makers may also seek to lower emissions in the transportation and heating sectors. The grid is likely the most efficient delivery system for industry-wide renewable energy.

Bulk transmission facilitates the ability of grid operators to take advantage of non-coincidental generation patterns throughout the regions. Variable generation from one location is increasingly being used to offset the variability of another in a geographically distant one. [26][27] This exploitation of the uncorrelated variability of renewable generation over wide geographies in order to make integration easier can be expected to continue as a strategy for maintaining grid reliability and enhancing asset use. In RTOs this is facilitated by consolidated control and real time markets. In areas without RTOs, the emergence of market coordination initiatives such as the CAISO-PacifiCorp energy imbalance market are enabling grid operators to gain access to complementary resources.

Siting and cost-allocation for these crucial resources remain challenges, and the need for new transmission could vary from modest to great. In a recent report, The North American Electric Reliability Corporation (NERC) cited the need for entities to more than double the average number of transmission-miles constructed over any five-year period since 1990 to meet planned levels of development over the coming ten years.[28] Based on NERC's analysis, this expansion will be critical towards accommodating a variety of new, clean energy supplies located far from electric load centers. But can so much new transmission be justified both operationally and financially? Can it be sited efficiently so it is available when it is needed? How can modernization and expansion occur at least cost (and be best justified)?

Getting the most out of what we have

Another major consideration in accomplishing modernization and expansion at least cost is using the existing system better and building what we do construct today to meet both present and future needs. How can we take better advantage of existing transmission assets? Can the capacity of transmission corridors we have now be increased to avoid having to create new rights of way? Can we optimize and operate the system more efficiently so variable resources can be more easily integrated, reserves and flexible capacity can be shared, and available transfer capacity freed up? As we phase out high carbon resources, such as uneconomic coal-fired power plants, does that open up transmission capacity that can be used by cleaner energy resources? Will transmission be located in the right place to

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[26] D. Corbus, D. Hurlbut, P. Schwabe, E. Ibanez, M. Milligan, G. Brinkman, A. Paduru, V. Diakov, and M. Hand California-Wyoming Grid Integration Study *Phase 1—Economic Analysis,* National Renewable Energy Laboratory Technical Report NREL/TP-6A20-61192 March 2014

[27] Jonathan Naughton, Thomas Parish, and Jerad Baker, Wind Diversity Enhancement of Wyoming/California Wind Energy Projects, Wyoming Infrastructure Authority, January 2013

[28] See NERC's 2013 Long-Term Reliability Assessment http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2013_LTRA_FINAL.pdf

accommodate new generating resources? Will sufficient essential reliability services be available and transportable to maintain reliability?

There are other significant practical constraints and considerations that need to be taken into account. In some cases new rights of way will need to be established and transmission built. If they can be planned and located to avoid or mitigate environmental and cultural resource conflicts, the prospects for building them will be greater, and recent DOE-funded tools including those developed at the Western Electricity Coordinating Council by their Environmental Data Task Force (EDTF) and Argonne National Laboratories for the Eastern Interconnection States Planning Council[29] can help address these challenges at the planning level.[30][31]

Transmission Technologies Needed

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 failures cause power outages much less frequently than distribution equipment. However, when the transmission system does fail, there is a potential that many more customers may be affected, and outage costs can extremely high, though as Superstorm Sandy showed, distribution equipment-related outages in extreme events can be just as disruptive and difficult to address. The higher cost per mile or per piece of transmission equipment, has historically led to greater attention to transmission system reliability, though hardening and speeding restoration of the distribution system in storm and flood prone areas has gained new urgency.

Technologies are needed in the transmission system to increase its functionality, as well as to accommodate load-growth, renewables and to correct-deficiencies. This includes several categories of technology whose functionality overlaps significantly between both the transmission system and its substations, some elements of the distribution system described later, as well as enterprise level functions, such as cyber security and back office systems.

A number of "smart" technologies are under development or in early deployment which will improve flexibility, capacity and system operation. Among these, monitoring of transmission assets is more cost-effective and beneficial than any other asset class (EPRI 1016055). Although transmission lines are one of the critical core backbone elements of the power grid, thousands of miles are unattended and not monitored in any way. Transmission lines have seasonal ratings that need to be considered by operations and planning. For the most part, there is little if any real-time monitoring other than at substations that provide operators with loading information.

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[29] To see the study and data viewer go to: http://eispctools.anl.gov/

[30] Carl Zichella, Johnathan Hladik, "Siting: Finding a Home for Renewable Energy and Transmission, America's Power Plan," The Electricity Journal, Volume 26, Issue 8, October 2013, Pages 125–138

[31] For a summary see Western Electricity Coordinating Council, WECC 2013 Interconnection-wide Transmission Plan, pp 33 -34, November, 2013

Other key Smart technologies include; supervisory control and data acquisition (SCADA); Phasor measurement units (PMUs); Flexible AC Transmission Systems (FACTS), energy storage, and micro-grid technologies. The Companion EAC Paper on R&D Needs explores these and other technology needs in detail.

Distribution Grid: modernization leads toward an Integrated Grid

Background

Utility distribution systems continue to be challenged by an aging infrastructure, conventional designs, and customer self-generation. Electricity distribution utilities are under pressure to improve system performance, in response to customer demands for higher reliability and power quality. Budget and investment constraints require electric utilities to manage their distribution systems even more efficiently. In addition, present expectations require that distribution systems support increased automation, new load types, increased penetration of DER, particularly distributed generation and storage, increased demand-side controls, environmentally friendly (green) technologies and are increasingly able to withstand damage from extreme events and/or to recover from those events.

One important need will be to accommodate DER in conjunction with traditional and evolving central generation resources in an "Integrated Grid." The Integrated Grid could assist in enabling wider-spread adoption of DER and offer consumers and utilities the opportunity to leverage the benefits of both central and distributed resource so as to provide affordable, reliable and environmentally sustainable electricity to consumers.[32]

The 21st Century distribution infrastructure needs to focus on addressing these challenges and enabling utilities to manage their distribution assets, reduce operations and maintenance costs, increase integration of microgrids and new supply technologies, and improve system reliability and performance while facilitating development of the integrated grid. In addition utilities need guidance on deploying infrastructure technology (monitoring, communications, computing, and information management) to support advanced applications, automation, and system integration that will enhance system operations and maintenance and enable applications to manage demand response and energy efficiency.[33]

To enable the wide-scale deployment of distributed energy resources while meeting the increasing demand of all consumers, two major areas of technology development must be pursued: (1) technologies which improve system responsiveness, flexibility and functionality; and (2) technologies which specifically are focused on enabling the integration of distributed energy resources.

[32] The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources," EPRI, Palo Alto, CA 2014

[33] Distribution Research Area Strategic Plan: September 2010. EPRI, Palo Alto, CA: 2011.1022335

Distribution Planning for Flexible Load Shape

It is becoming more common that utility distribution planners are faced with accommodating a large penetration of local generation and storage on their power distribution circuits. In many states, the renewable portfolio standards and incentives from various sources coupled with decreasing costs and improved performance of DER have resulted in larger DER installations than previously experienced.

The distribution planning process has traditionally been focused on determining the least cost alternative for meeting the peak load demand projected for some date in the future. The analysis is often simplified because loading patterns have been the same for many years, and there is much experience with dealing with these loading patterns such as for the rating of transformers.

By looking at how the system behaves at one loading point, the planning engineer has a good idea of how it will respond at other times. The basic process can be summarized as follows:

- Define a distribution planning area (DPA) and model it for power flow analysis
- Develop a load forecast for a selected planning horizon
- Determine when planning limits on voltages and current capacities will be exceeded based on the load forecast
- Identify one or more alternatives for correcting the violations.
- Determine the least cost alternative over the planning horizon using approved economic evaluation methods.

These methods alone are no longer sufficient. Expanding and modernizing the distribution systems for the 21st century will require advances in:

- Distribution real-time modeling and simulation
- Modeling the performance of smart inverters
- Understanding how today's distribution management systems need to evolve.
- Understanding how best to use automated metering infrastructures (AMI) in a flexible load shape environment.

Distribution System Responsiveness, Resiliency, Flexibility and Customer Connectivity

The modernized distribution system must become flexible; able to respond to changing system conditions; able to communicate real-time information; easily and efficiently accommodate varied generation and load types; able to easily accommodate the installation of new equipment and equipment types; and to support system and end-use energy-efficiency and demand response initiatives.

The following are key components for achieving this future state:

- Utilities will be prepared to accommodate distributed generation, storage, and plug-in hybrid electric vehicles as well as other new, as yet unanticipated devices.

- Intelligent distribution devices will support plug-and-play capability
- The distribution system will be designed with devices to manually or automatically respond to meet changing system conditions (demand needs, fault conditions, and so on).
- Utilities will use the Smart Grid infrastructure to accomplish core distribution tasks.
- Distribution designs and protection schema that address anticipated increasing of distributed generation, storage and PEVs.
- Provision for visualization, operation and control of distributed generation, if it is part of a total capacity plan.
- Incorporation of distribution designs and protection that accommodate microgrids.

These applications involve implementation of monitoring equipment (sensors), communication infrastructure, and advanced protection and control functions. The improvements will support utilities in the migration to distribution management systems with model-based management of the system. The Distribution Management System (DMS) of the future will need to integrate many functions to optimize system performance, reduce losses, optimize voltage and VAR control, improve reliability through system reconfiguration and fast restoration and integrate distributed resources.

Distribution Technologies

Many challenges are impeding the implementation of advance distribution technologies, including (1) existing designs and conditions of distribution systems that are not yet ready to support smart applications, (2) the need for plans for an orderly application of smart technologies, (3) standards and protocols for the technologies, (4) the need for plans and methods for investment cost allocation, and (5) justification for capital investments by utilities. In addition, new load and generation types are being added to the grid, creating an urgent need for the dynamic system response enabled by smart applications.

The following are key components for achieving this future state:

- Distribution planners will have the data, experience, and needed modeling tools to plan for different renewable-deployment scenarios.
- Methods to determine feeder hosting capacities for Storage, PEVs and variable distributed generation will be available.
- Distribution operators will (i) know what distributed energy resources are connected to their systems, (ii) be able to forecast and manage variability, and (iii) be able to employ mitigation strategies when needed.
- Distributed generation systems will include power and communication interfaces that are able to provide grid support.
- Communication protocols and interfaces will be available for distribution management systems and will be able to take advantage of advanced functions available from electronic inverters.
- Effective business models for utility ownership and operation of distributed energy resources will be available.
- Utilities that own and operate DER systems will have established practices to minimize operation costs and avoid downtime.
- An improved understanding of the nature of distributed generation variability relative to wind or solar variability. What are typical ramp rates? Ramp magnitude/duration? Diversity benefits?

- Improved definition and utilization of use control options in power electronic interfaces of PV and small wind turbines for grid support.
- The development and validation of improved steady-state, dynamic, and short-circuit models.
- The development of new planning and operation methods and tools that consider the variability of output across time.

The integration of high levels of distributed renewable generation resources into the distribution system will require nimble management processes, use of highly automated and flexible distributed smart devices, and workforce training to uphold safety and reliability standards. A future grid network with increasing distributed energy resources will need to have the following attributes:

- Communication, metering, and power interfaces of distributed renewable to provide grid support, including the required communication protocols for integration.
- Smart technologies (such as inverters and energy-storage devices) and advanced measurements and controls (such as self-diagnosis and self-healing).
- Existing and emerging intelligent technologies and techniques to provide for proactive maintenance, optimal levels of asset use, and greater efficiencies.

The increased applications of distribution generation and the application of demand-response initiatives as additional tools to meet capacity requirements will further challenge the distribution system. As the composition of the system changes, utilities will maintain the responsibility to meet demand with increasing efficiency, reliability and quality.

The Companion R&D paper describes the specific technologies needed and highlights their functionality.

Summary

The 21st century transmission system will need significant improvements in order to continue to provide reliable, economic electric service to the nation's residential, commercial and industrial customers. A sea change in the types and characteristics of energy generation sources is underway on both the bulk electricity and distribution systems. The factors influencing these changes include major shifts in the fuels available to the system, the costs for those fuels, the environmental sustainability of the fuels, and the challenges in managing the incremental system flexibility requirements stemming from the integration of variable energy resources. Operating a system that changes rapidly in terms of both load and generation requires an upgrade in information technology, system communications and operational architecture, evolving markets and business models. DOE has already played a leading role in defining some of these challenges and needs to continue its efforts to accelerate research, development and commercialization of the new technologies, operational techniques and system architectures. The goal is a modernized system meeting the needs of the American people, and which is able to integrate new generation and storage resources and control and operational technologies both known and as yet unknown, that will certainly emerge in the decades ahead. At the same time, policymakers and stakeholders recognize that, from a cost and technical standpoint, a more integrated grid will cost a lot of money and take decades to implement.

Recommendations

Strategic Opportunities

To maintain this momentum, organizing appropriate interests to address the following broad categories of issues:

- **Develop Future Grid Operating Systems:** Management and control of the grid, from the largest transmission interconnection down to the neighborhood micro-grid, is a 'system of systems' problem that requires continuous updating to incorporate system characteristics, market and technology development.
  - ***DOE recommendation*****:** Work with the industry to define the architecture of the next generation EMS and DMS and create standards that drive the implementation of an 'open systems architecture'
- **Improve Power Flow Control:** The efficiency of the transmission grid can be improved by advancement and strategic use of power flow control technologies. Cost-effectiveness of this technology is a key prerequisite to reduce transmission line congestion and provide needed capabilities to the grid.
  - ***DOE recommendation:*** Fund a demonstration project that illustrates the efficiency gains from deployment of advanced power flow control technologies
- **Create Smarter, More Resilient Distribution Systems:** Maintaining the reliability and resiliency of the grid against natural disasters, extreme weather, and cyber and physical-attacks requires new economic solutions. Advancing automation, micro-grids, and other concepts can mitigate the number and scale of outages during an event and facilitate more rapid recovery.
  - ***DOE recommendation:*** Research and report on strategies to harden and make more resilient grid assets in response to credible potential threats, both natural and man-made. Work with other federal agencies to inventory and characterize vulnerabilities and lessons learned from microgrid development projects such as those being established by the Department of Defense
  - ***DOE recommendation:*** Identify and assess other strategies to assure the continued provision of critical social services when grid power is disrupted.
- **Integrate Multiple Systems and Technologies:** Demonstration of integrated solutions using new and current technologies (including DER, storage, DSM) is needed to speed deployment and acceptance. Improving the understanding and characterization of how different technologies interact within the system of systems (toward which the grid will likely evolve) is vital to effective operations and planning.
  - ***DOE recommendation:*** Continue to prioritize and provide funding for research and development on variable resource integration and energy storage applications. Collaborate with industry and university research efforts to identify, evaluate and promote the development of technology advancements and operational enhancements needed to lead toward the Integrated Grid. (*See companion R&D paper for more specific recommendations).*

- **Design and Plan the Future Grid:** The planning tools and methods used for the grid need to be architected to handle new sources of generation, new grid technologies, and new system frameworks. This includes looking beyond the typical near-term planning paradigm to review the cost effectiveness of adopting non-standard technologies.[34]
  - ***DOE recommendation:*** As previously recommended by the DOE EAC the Department should to continue to work with regional and interconnection-wide planning and reliability entities such as RTOs, the Western Electricity Coordinating Council, Peak Reliability, and the Eastern Interconnection Planning Collaborative to take advantage of DOE research and development products as these entities develop planning tools and methods needed to reliably expand and modernize the 21st century grid.
  - ***DOE recommendation:*** Coordinate with abovementioned entities, ERCOT and FERC regional planning entities to ensure that emergent technology, grid coordination, and operational advancements are included in their regional and interregional planning efforts as required under FERC Order 1000 non-wires alternatives analysis and consideration.
  - ***DOE recommendation:*** Work with industry to support the development of guidelines and Interconnection standards (macro and micro level), both communications and full grid interaction ability of any device connected to the grid.
  - ***DOE recommendation:*** As the modernized grid will be needed to support greater integration of renewable generation, and national, environmental and economic goals, DOE should study the means to improve efficiency and reliability through strategic electrification of end uses, including thermal and transportation uses.

[34] See, for example, WECC and EIPC planning processes, as well as FERC Order 1000 regional planning requirements including non-wires alternatives, and public policy goals in determining drivers for transmission alternatives.

Appendix A: Smart from the Start[35] Policies and Criteria

Smart from the Start Siting Policies and Criteria

- Consult stakeholders early and involve them in planning, zoning and siting.
- Collect and use geospatial information to categorize the risk of resource conflicts.
- Avoid land and wildlife conservation conflicts (including national parks and other protected areas) and prioritize development in previously disturbed areas.
- Avoid cultural resource conflicts (historic sites, tribal resources, etc.).
- Identify excellent renewable energy resource values.
- Establish, when possible, pre-screened resource zones for development .
- Incentivize resource zone development with priority approvals and access to transmission.
- Consider renewable energy zones or development sites that optimize the use of the grid.
- Maximize the use of existing infrastructure, including transmission and roads.
- "Mitigation that matters" (durable and planned conservation improvements at larger scales).
- Where zoning is not feasible (as in much of the Eastern Interconnection), use siting criteria based on the above principles.

The Smart from the Start approach is valuable for siting both generation and transmission, but is most effective when used for both at the same time. It can also be helpful in delivering efficient use of existing transmission resources.

Two of the Smart from the Start principles are particularly important for accelerating renewables:

- Establish, when possible, pre-screened resource zones for development.
- Where zoning is not feasible (as in much of the Eastern Interconnection), use siting criteria based on the above principles.

Establish renewable energy zones

Pre-screened zones for renewable energy can dramatically accelerate time to market for new generation. This streamlines siting hurdles for all projects involved, and can help government agencies prioritize projects and work together to assess impacts efficiently and bring new infrastructure online more quickly.

Texas pioneered renewable energy resource zoning in 2005 to develop transmission for remote wind energy projects. Today, nearly 11,000 megawatts of wind capacity have already been constructed in Texas, and the state expects to add at least 18,500 megawatts more. The Electricity Reliability Council of Texas (ERCOT) is responsible for developing the transmission, and has estimated that up to 3,500 miles of new lines are needed to bring the new wind capacity to the state's load centers. Texas' proven renewable energy zones will be critical to making this happen.

[35] Carl Zichella, Johnathan Hladik, "Siting: Finding a Home for Renewable Energy and Transmission, America's Power Plan," The Electricity Journal, Volume 26, Issue 8, October 2013, Pages 125–138