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IEEE JOINT TASK FORCE ON QUADRENNIAL ENERGY REVIEW

SUMMARY
of
IEEE REPORT TO DOE QER ON PRIORITY ISSUES

Prepared for

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Washington, DC
September 5, 2014

IEEE

PREFACE

President Obama issued a Presidential Memorandum in January 2014 directing several Federal agencies to undertake a Quadrennial Energy Review and report back in January 2015. The US DOE, under the leadership of the White House Office of Science and Technology Policy and the Domestic Policy Council, has requested IEEE to provide insights on a specific set of priority issues: effects of renewable intermittency on the electric power grid and the potential role of storage; utility and energy company business cases related to microgrids and distributed generation, such as rooftop photovoltaics; the technical implications of electric vehicle integration; asset management including aging infrastructure; metrics for Smart Grid; skilled workforce issues; and condition and performance of the electric grid.

Indeed, the questions raised by DOE span some of the major issues facing the electric power sector world-wide. The National Academy of Engineering considers electrification as the first of twenty engineering achievements that have had the greatest impact on quality of life in the 20th century. Presidential Policy Directive 21 identifies the Energy Sector as uniquely critical because it provides an “enabling function” across all critical infrastructure sectors. Modern society has reached a point where virtually every crucial economic and social function depends on the secure, reliable operation of the power and energy infrastructures. These infrastructures provide huge societal benefits but also face big challenges. International energy industry has been experiencing significant changes caused by new technology trends, environmental concerns, new weather patterns, changing consumer needs, and regulatory requirements. The electrical power and energy sector will continue evolving as consumer expectations and options will change, technology breakthroughs will happen, and energy sources and their usage will be transformed. Use of electricity is expected to grow even with improvements in energy efficiency as it is expected that electrical energy will replace other forms of energy (e.g. transportation).

IEEE, the world's largest professional organization dedicated to advancing technology for humanity, utilizes synergies among private and public sectors (utilities, vendors, academia, national labs, regulatory organizations, and other industry participants) to provide unbiased and independent technical leadership to electrical power and energy industry worldwide. Spearheaded by the IEEE Power & Energy Society (PES) and IEEE-USA, IEEE Joint Task Force leaders engaged a large IEEE volunteer community to compile and review this report. Contributors to this report include:

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EXECUTIVE SUMMARY

This report was prepared by IEEE in response to a set of specific questions posed by U.S. DOE with a request for IEEE insights into these priority issues. The team endeavored to keep the responses within the scope of the questions. There are many other grid-related issues that are not addressed here.

The past few years have brought about great strides in advancing knowledge on all fronts of interest to DOE. This pace of progress is expected to continue and the report should therefore be viewed as a snapshot reflecting the knowledge available today.

Responses discussed in this report are highlighted below.

Effects of renewable intermittency on the electric power grid and the potential role of storage in addressing these effects

- **The bulk power grid can accommodate a large amount of intermittent generation**, although it would require some changes in planning and operating procedures.
- **Grid-level energy storage is a beneficial resource but it is a grid resource and its absence is neither a barrier to nor is its availability per se an enabler for penetration of renewable energy.** Solutions involving curtailment or flexible generation are currently less expensive than energy storage.
- **The distribution system issues** are more complex **--** intermittent renewable generation creates many new challenges, not experienced with conventional distributed generation.
- Alternative engineering designs, technology solutions, and new and updated planning and operations practices are needed for the **distribution system of the future, which treats renewable or other distributed generation as an intrinsic component and shifts the focus from mitigating impacts or restricting proliferation to fully exploiting their potential benefits**.

Utility and other energy company business case issues related to microgrids and distributed generation (DG), including rooftop photovoltaics

- **Microgrids and distributed resources should be viewed as integral elements of the overall electrical grid.** Traditional grids and microgrids should be purposefully integrated into hybrid grids to fulfill all the consumer needs, with transmission as an enabler to support integration of renewable resources.
- **The microgrid business case depends on benefits achieved for the consumer and the provider**. Key aspects include costs, efficiency, reliability, safety, and resiliency -- all supported by and coordinated with the balance of the grid in a manner that enables the utility or energy company to defer more expensive investment or to manage its grid in a less costly manner.
- **Policy should support value creation**, with results-based rewards, and not unduly favor either incumbent utilities or non-utility microgrid sponsors.

The technical implications for the grid (bulk and local distribution) of electric vehicle (EV) integration - and the timing you see as necessary to avoid having the grid status slow down any potential progress

- **The generation and transmission systems can handle millions of plug-in electric vehicles.** Some recent studies indicate that the number could be between 8 and 12 million without any need for additional capacity. Although not a realistic expectation, even electrification of the entire passenger fleet would only add about 10% to U.S. electricity requirements.
- **There is a good understanding of technical issues that may arise on the distribution system.** Generally, the issues relate to potential overloads of distribution transformers and circuits, changes in equipment cooling patterns, or inability to accommodate high-power charging in older neighborhoods with legacy distribution infrastructure.
- **The recommendations include distribution system upgrades, development of PEV charging infrastructure, battery research, and development of modeling and control tools.**

The implications and importance of aging infrastructure and the options for addressing these challenges, including asset management

- **Aging infrastructure should not be treated as an isolated concern**; rather it should be viewed in the context of holistic asset management.
- **The entire equipment fleet must be managed to achieve system reliability and meet customer service needs** through effective planning and operations.
- **Holistic approach** in support of business goals includes management of **Aging Infrastructure** (including condition monitoring and assessment tools), **Grid Hardening** (weather related response, physical vulnerability and cyber security), and **System Capabilities** (including reliability improvements).
- **Urgently address managing new Smart Grid assets** such as advanced metering infrastructure and intelligent electronic devices.
- **Investigate practical measures to shorten times to replace and commission equipment that failed due to extreme events, physical attacks, or other reasons.**
- **Better coordination of electricity and gas markets**, including developing operational tools to more accurately forecast the availability of natural gas supply for generators and improve unit commitment decisions**.**

Recommendations for metrics for addressing Smart Grid issues, especially to help policy makers determine the importance and necessity of protocols

- **A Smart Grid metric and any figure of merit depend on the definition of the Smart Grid**, particularly expectations as to what will be facilitated by the Smart Grid, and reflect the perspective and the framework of the stakeholder.
- Two sets of metrics are recommended: one driven by electricity users' needs and preferences and another, driven by national, regional, and state priorities.
- **Timely development of standards and protocols is key to implementation** of Smart Systems. Selected Smart Grid standard development must be put on a "fast-track".

Skilled workforce issues

- **Workforce implications and educational or training needs should be considered as integral factors of research and policy initiatives.**
- **A range of partnerships** (examples included in the report) should be formed to develop new curricula and enhance secondary and post-secondary energy sector workforce training programs, apprenticeships, and use of best practices. This includes participation of individuals in standards development, professional activities and conferences, and continuous education.

Report cards on the condition and performance of the electric grid

- *This topic is too extensive to be addressed in detail at this time. It is planned to be addressed in the future.*

Observations common to many of the topics addressed:

- Institutional challenges can be serious barriers to engineering solutions.
- More emphasis on accelerated development of industry consensus standards.

In conclusion, the IEEE has delivered to DOE QER:

- This summary report consisting of individual summaries for each topic, including key findings and recommendations.
- The overall report with detailed information on each topic.

This document has been extensively reviewed by the IEEE membership, IEEE PES Technical Committees, representatives from various industry organizations (including APPA, EEI, UWIG), NERC, utilities, RTOs, academia, and private companies. The IEEE team has incorporated those extremely valuable comments to the best of its abilities while assuring document consistency. This report is also accompanied by set of slides for each section to help illustrate the findings and provide information in a graphical form.

Summary Reports on Priority Issues

1. Effects of Renewable Intermittency on the Electric Power Grid and the Role of Storage

At low levels of penetration of intermittent (variable and uncertain) renewables, their variable and uncertain output is not a serious issue and storage is not essential as bulk power systems are designed to accommodate the inherent uncertainty of load and deal with the contingencies of unexpected equipment outages.

At higher penetration levels, mandated by some state Renewable Portfolio Standards (RPS) extensive studies and real world experience integrating intermittent renewables in the USA power system, **up to annual energy penetration levels of around 30%**, **have shown that the variability and uncertainty can be tolerated if traditional power system planning and operations are updated**. This assumes availability of options such as demand response and fast responding conventional generation along with expansion of transmission and consolidation or coordination of balancing areas (authorities) to reduce the impact of variability through integration over larger footprints and reduce uncertainty through more frequent and accurate forecasts of renewable output. These changes are beneficial to power system operations and economics even if an RPS mandate is not imposed on that particular power system.

Operational impacts of intermittent renewables include changes in **voltage and reactive power management, frequency regulation, and transient behavior of the system.** Additional studies of such impacts at various levels of renewable integration are required for proper planning and operation of the power system. System reactive power support needs to be provided either by renewable generation with dynamic voltage control or by conventional generation and dynamic reactive power sources (such as Static VAR Compensators and Static Synchronous Compensators). Fast detection of dynamic voltage instability conditions and proper mitigation methods are needed to prevent large system outages. Proper frequency regulation requires enough spinning reserve to accommodate wind ramps and to address impacts of difference in inertia of renewable generation, compared to conventional. Modern technology, including smart inverters and advanced wind turbine controls, helps solving the above technical issues, but requires additional **investments in equipment capital and O&M costs, better grid monitoring, and implementation of appropriate interconnection standards.**

There are other unresolved issues such as the **institutional challenges of transmission expansion, balancing authority consolidation or cooperation, jurisdictional authority, cost allocation, adequate revenues for conventional generation as well as a plethora of market design challenges and regulatory and government policies.**

At these same levels of penetration, energy storage, while a useful and flexible tool for managing the grid, is not essential as other, often more cost-effective, options are available such as fast responding generation, curtailment of the intermittent generation, and demand response. Further, the studies show that curtailment is simply less expensive than energy storage. **Energy storage is a beneficial resource but it is a grid resource and its absence is neither a barrier to nor is its availability *per se* an enabler for penetration of renewable energy.** Energy storage efficiency is a function of the specific technology and can result in energy losses in the 15-35% range. These energy losses are in the range of curtailment of intermittent resources seen in many integration studies at these levels of penetration.

Pursuit of levels of penetration approaching 100% of the energy supply is generally driven by policy considerations. Output from wind generation at these levels will often exceed load, especially during the seasons of high wind. Output from photovoltaic (PV) generation at these penetration levels may greatly exceed load during minimum daytime loading conditions, especially in the spring and fall. Incremental PV additions at these penetration levels have a declining economic value unless truly affordable energy storage becomes available. Here the first principle is that energy storage needs to be cheaper (total costs including capital and O&M) than the alternative generation source. The results of most studies at these very high levels of intermittent renewables result in storage duration (length of discharge at rated power) needed to achieve nearly 100% penetration levels (all energy needs supplied by intermittent renewables) in hundreds of hours -- effectively seasonal storage. Electricity storage at these levels is generally not affordable at present cost of storage.

Most of the studies of these very high levels of penetration result in requirements for very long duration storage and substantial storage capacity to match the variable renewable output to the time varying load. An alternative solution is very large excess capacity of intermittent renewable generation (nameplate rating of 200-300% of peak load) and very significant curtailment when the generation from intermittent renewables exceeds the load. While this solution may be surprising to some, it is essentially the solution that emerges at intermediate penetration levels. **Until storage is significantly cheaper, excess generation and planned curtailment appear to be more economical.** Further exploration of these results may provide more insight.

On the distribution system, high penetration levels of intermittent renewable Distributed Generation (DG) creates a different set of challenges than at transmission system level, given that distribution is generally designed to be operated in a radial fashion with one way flow of power to customers, and DG (including PV and wind technologies) interconnection violates this fundamental assumption. Impacts caused by high penetration levels of intermittent renewable DG can be complex and severe and may include voltage increase, voltage fluctuation, interaction with voltage regulation and control equipment, reverse power flows, temporary overvoltage, power quality and protection concerns, and current and voltage unbalance, among others. These impacts may be mitigated using a combination of conventional and advanced solutions. **Distributed energy storage, particularly battery storage systems, advanced power electronics-based technologies, such as distribution class FACTS devices, and increased real-time monitoring, control and automation** can play an important role in alleviating these issues and facilitating integration. Moreover, updated modeling, analysis, design, engineering, planning and operations practices are required to facilitate integration and ensure reliable and secure operation of increasingly active and dynamic modern power distribution systems. It also includes accuracy of information that is entered into the model. As the common piece of equipment that couples the energy source to the grid is the inverter, detailed inverter models are required to benefit from improvements made in software modeling tools.

Because of the very substantive differences and needs for transmission and distribution systems, the detailed discussion below addresses the two topics separately.

Recommendations

Support technology R&D and standards development

- Promotion of new initiatives and support of existing R&D activities for development and implementation of advanced functions in smart inverters.
- Power electronics-based equipment to replace or complement conventional transformers, load tap changers, voltage regulators, and capacitor banks for more efficient voltage regulation and control on the distribution system.
- Low-cost distributed energy storage technologies and other solutions such as demand response to facilitate integration of high penetration levels of intermittent renewable DG in the distribution grid.
- Modern and future distribution system designs that are suitable for active and highly dynamic grids and consider DG as an intrinsic component, and corresponding analysis, engineering, planning and operations practices.
- Unified and enforced renewable generation interconnection standards based on analysis of operational (including dynamic) system conditions to define necessary integration requirements.
- Interconnection standards for integration of distributed energy resources and implementation of concepts such as microgrids in distribution systems.
- Standards and common practices for using and handling large volumes of data available from real-time-measurements, e.g. synchronized measurements, as well as business case for justifying use of those measurements based on application needs, particularly at the distribution level.

Support software development

- Software tools and processes for renewable resource forecasting, energy load forecasting and market price forecasting.
- Software tools and processes for real-time, coordinated and integrated operation of distribution, sub-transmission, and transmission systems (e.g., EMS/DMS).
- Improvements in current software tools and accuracy of input data for
    - Comprehensive modeling and analysis of distribution systems with high proliferation of DG, e.g., development of joint models for steady-state and dynamic/transient analyses, and development of detailed models of DG inverters
    - Integrated modeling and analysis of distribution, sub-transmission, and transmission systems that lead to more consistent results among these power system components

Foster coordination across jurisdictions

- Resolve technical and jurisdictional issues associated with devices, such as batteries and PV inverters, that simultaneously serve both the distribution and transmission grids; and operate across institutional, regulatory, and information architectural boundaries.

- Support and accelerate, as practicable, regional and interconnection-wide transmission planning practices and system operating procedures, to support integration of intermittent renewable generation for public benefit.
- Support a multi-agency State and Federal Collaborative to develop model regulations and integration policy to plan for operational issues (e.g., voltage fluctuation, bidirectional power flows, etc.) to promote the most efficient deployment of variable generation.
- Explore opportunities for collaboration in existing projects and support new joint projects with existing network of industry's R&D organizations such as PSERC, EPRI, APPA, NRECA, etc.

2. Utility and Other Energy Company Business Case Issues Related to Microgrids and Distributed Generation (DG), Especially Rooftop Photovoltaics

Technology innovation, decreasing costs and consumer interest in improved power reliability, resiliency and sustainability have led to **increased uptake of distributed generation (DG), primarily solar photovoltaics (PV), but including standby or backup generation**. These trends are expected to drive the microgrid market as utilities seek to manage DG – and capture other microgrid benefits – and energy service companies (ESCOs) and other sponsors seek similar goals.

Utilities need to adapt to and compete with the ESCO- and customer-initiated challenges, which may require a new business model. Meanwhile, utilities are likely to implement microgrids for their own business and operational purposes. They may find that non-utility microgrids can serve their purposes as well, as the latter can provide manageable loads, an alternative source of supply and ancillary services such as voltage control and frequency regulation. Beyond managing the operational impacts of high DG penetration, **utilities can also employ microgrids to defer capital investment in additional capacity, manage problematic circuits and address localized load growth, as well as respond to customer interest in improved resiliency and operational continuity during unexpected outages and extreme weather events.** On the business side, microgrids may also enable a utility to offer customers differentiated quality-of-service options and participation in transactive energy markets. On the policy front, utility-sponsored microgrids can help meet the requirements of energy efficiency, peak load-reduction and load-shaping programs, as well as assist in meeting renewable portfolio standards (RPS) and goals for lower carbon emissions.

In this new mix of utility and non-utility players, **traditional grids and microgrids should be purposefully integrated as hybrid grids**. In the context of hybrid grids, transmission is an enabler to their deployment, providing pathways for the transport of clean energy between resource and demand centers, providing the vehicle for resource movement and delivery, while at the same time fortifying electric system efficiency and stability and reliability of supply. Integration of distribution-based resources and micro-grids can increase efficiencies in the use of the existing grid, as well as become part of the overall development strategy to balance the supply and demand uncertainties and risks with a variety of different resources.

A positive microgrid business case for utilities, ESCOs and others depends on apportioning quantifiable benefit streams against costs among all stakeholders. As the performance of power electronics, PV panels and energy storage technologies improve and costs continue to drop and policy adapts to enable new business models, the market for both utility-sponsored and third-party microgrids is likely to expand. The increasing uptake of distributed generation at commercial/industrial and residential premises, largely in the form of rooftop solar PV systems, is driven by several factors.

First, improvements in solar photovoltaic performance, coupled with dropping prices, innovative financing and federal and state policy incentives have made the technology more accessible and affordable with a shorter payback period for utility customers. **Second**, customers are seeking more control of their energy destiny in response to an aging, less reliable grid, extreme weather events, uncertainty over costs, and a desire to reduce their fossil fuel-related carbon footprint.

The current and projected growth in microgrids is a separate but related trend occurring among large utility customers captured by the acronym MUSH. Military installations, universities, schools, and hospitals – as well as other civic institutions and corporate campuses – increasingly require improved energy surety, reliability, and resilience. Microgrids can provide large utility customers with the ability to manage distributed generation (DG) in the form of diesel- and natural gas-driven microturbines and generators, solar PV, and other renewable energy sources, prioritize and manage loads and achieve a degree of autonomy from the grid through self-sufficiency and, during grid outages, by "islanding" – operating apart from the grid – during grid outages.

Utilities are rightly concerned that greater customer autonomy will reduce traditional, regulated revenue streams that depend on cost-of-service rate making and volumetric pricing. Regulated utilities are often incented to achieve a rate-of return from investment in infrastructure and sell electricity by the kilowatt hour. Utility concerns over revenue could be allayed if utilities developed a positive business case for implementing their own microgrids and optimally integrating non-utility microgrids, while obtaining regulatory rewards for quantifiable customer benefits unrelated to infrastructure investment and volumetric electricity sales. **A comprehensive understanding and quantification of microgrid-related benefits and costs is needed to drive a new multi-stakeholder policy and regulatory paradigm**. Relevant policies, however, are developed at the state level, which creates a national policy patchwork – adding an additional level of complexity for utilities with multi-state operations. In contrast, technology standards – at least in concept – tend to be global in nature. Though fundamental standards related to grid-microgrid interconnections and other operational needs have been articulated and adopted, existing standards are being reviewed and revised and gaps identified and addressed.

From the utility perspective, high PV penetration and non-utility microgrid implementations shift the legacy, centralized, unidirectional power system to a more complex, bidirectional power system with new supply and load variables at the grid's edge. This shift introduces **operational issues such as the nature, cost, and impact of interconnections, voltage stability, frequency regulation, and personnel safety,** which in turn impact resource planning and investment decisions. Research and current implementations are expanding the toolkit available to utilities to address these emerging issues.

Taken together, these myriad issues mean that a positive utility business case for microgrid implementation is a complex calculus that includes evolving technology (including controls, protection, and energy storage), policy, and standards. How utilities address microgrids – useful asset or disruptive force? – may reflect how they handle the larger, shifting market landscape that may include flat load growth, rising costs, and competitive pressures. By developing a positive business case for sponsoring or accommodating microgrids, a utility may well envision its path to a **future-oriented business model that may include new product and service offerings and favors partnerships and collaborations over customer "ownership."** Microgrids in conjunction with intelligent resource management, demand side management (DSM), and demand response (DR) enable new business models in which users pay for the level of reliability, power quality, and overall service. The new models enable higher efficiency levels that contribute towards lower operation costs.

Recommendations

The IEEE QER Team recommends that a path to adoption of microgrids be fair to all stakeholders and supportive of clear, attractive benefits for the utility, which must cope with operational impacts. Where a microgrid is sought by a third-party developer or customer, utility accommodation should, at a minimum, not adversely impact the affected utility financially or operationally.

- Policy should support value creation, with results-based rewards, and not unduly favor either incumbent utilities or non-utility microgrid sponsors.
    - Assessing costs should include any measures that support efficiency, reliability, safety, optimizing life-cycle costs, and resilience for the grid.
    - Costs and benefits must be apportioned to each relevant party in a multi-stakeholder microgrid business case to accelerate microgrid adoption.
    - Regulatory policy must be reviewed and revised to reward a utility for the costs incurred in planning, operational changes, and the optimal integration of these customer- or utility-owned assets. New projects involving the gamut of stakeholders, including distribution utilities, should provide operational, safety, and financial insights to support the policy.
- Utilities need to review where and how best to accommodate microgrids and DG given existing policy, which could speed the review of DG and microgrid proposals. Operational impacts may include system frequency regulation, harmonics, and voltage support.
- Continue offering technology roadmaps and R&D investments (e.g., via U.S. DOE/DoD, national labs and selected pilot projects) to foster microgrid implementation.
- Utility business case-, operations-, and safety-related lessons learned from utility-sponsored microgrids developed with U.S. DOE participation under the ARRA should be documented and disseminated.
- Continue sponsoring R&D in power electronics applications (e.g., load tap changers, grid edge controllers), protection schemes, and microgrid controls to address operational challenges, including voltage and frequency regulation, from high penetration of DG.

3. The Technical Implications of Electric Vehicle (EV) Integration for the Grid, Bulk and Local Distribution

Hybrid internal combustion engine (ICE) electric drive technology vehicles (HEV) entered the USA market in 2000. Plug-in Electric Vehicles (PEV) have started entering the market very recently yet have already seen cumulative sales of nearly 250,000 and the Obama Administration has set a goal of one million PEVs by 2015. Plug-in electric vehicles (PEVs) are a class of vehicles which can be charged by electricity through an electric plug. Such vehicle types include:

- Plug-In Hybrid Electric Vehicles (PHEV) - similar to conventional HEV except for the ability to charge the battery directly from an electric socket, and a larger battery to enable driving on electricity
- Extended Range Electric Vehicles (EREV) - electric drive vehicles with fuel-engine-driven generators capable of recharging their batteries,
- Battery Electric-only Vehicles (BEV) - all electric drive vehicles with no supplemental engine

Most major automakers have a PHEV/EREV or BEV vehicle on the market or proposed. So far in 2014, conventional hybrids and PEVs are almost 3 percent of the market. To date, more than 3 million HEVs have been sold in the U.S. and nearly 1/4 million PEVs. A PHEV/EREV uses only a modest sized battery for an all-electric range of ten to 40 miles. The BEVs on the market today typically get around 60 to 80 miles per charge, though a Tesla can travel over 200 miles on a single charge. The battery for a PHEV/EREV has a capacity typically below 20 kWhs and represents an electric load less than that of an electric water heater. A BEV would have a larger battery – 1 to 5 times this size (this includes the longest-range BEVs, Tesla, with an 85 kWh battery for 250 miles). Because the average USA light duty vehicle (LDV) is driven less than 40 miles a day and the average trip is about 10 miles, **PEVs could serve about half of USA LDV miles by electricity.**

To help accelerate the adoption of the PEVs eight states have formed an electric vehicle compact. These states include California and New York and account for 28% of the total vehicle market in the U.S. The goal of the compact is to develop infrastructure, coordinated policies, codes and standards and a consumer market to put more than 3.3 million "zero-emission" vehicles on the roads in those eight states by 2025. This would be a tripling of the current pace of growth for electric vehicles. More than 1,000 public charging stations exist today and more than 14,000 are planned or under contract. Plugshare offers pointers to more than 50,000 charging locations in North America, which include many private chargers that the owners are willing to share with others who are traveling. On the West Coast, there is work underway to provide a North to South fast charging infrastructure that will allow a driver to make the drive from Mexico to Canada without having to wait for regular charging times. It is important to note that these "fast charging" stations are relevant only for the BEV that cannot recharge from the onboard ICE. For the PHEV/EREV fast charging is not really needed.

Early studies by PNNL and ORNL suggested that more than half of all LDVs could be powered by existing generation resources while more recent studies confirm that **eight to 12 million PEVs can be accepted into the current grid with little impact on generation and transmission** as most charging would occur off-peak (if desirable, charging off-peak could be accomplished through a combination of tariffs, built-in charging algorithms, demand limiters, or distributed controls). However, **some of the existing distribution infrastructure may not be able to accept PEVs without some rework.** The peak demand imposed by the PHEV/EREV and BEV on the grid depends on the size of the on-board battery, the owners' driving patterns, the charging strategy, and the charger characteristics. The more powerful chargers will result in much higher demand than that imposed by charging through a conventional plug. Several electric vehicles on one residential street could overload the local distribution transformer unless demand management measures are implemented to enforce load diversity and prevent a possible overload. There is ample experience with success of such controls, which have been widely applied to off-peak heating and water heating.

Recommendations

- **Promote the development of PEV charging infrastructure** and its deployment by cities, states, and businesses, and along the interstate highway system with the support of the federal government. Starting with a coast to coast infrastructure on major Interstate routes will allow people to have the ability to travel greater distances on electricity.
- **Promote battery research** focused on transportation focused on longer range and battery chemistries that allow the battery to be charged in an episodic fashion so that distributed variable resources can be efficiently used for charging.
- **Promote improved cost and efficiency of various converters**. One option still under research is eliminating dc-to-ac, then ac-to-dc conversions by allowing direct current transfer from distributed energy sources to the car. This development is not imminent and widespread adoption would require changing standards and building codes. IEEE's DC@Home initiative is currently looking at how to integrate DC distribution into homes and small businesses to avoid the conversion losses, addressing benefits (e.g. efficiency, reactive power issues) and concerns (e.g. voltage conversion losses and protection and safety issues).
- **"Fast track" IEEE and IEC standards and research to support higher penetration of PEVs in the grid.** The U.S. Government and especially NIST have an important role in helping with this process. Specifically, the proposed standards and research include:
    a. **Physical grid equipment**, primarily at the distribution level. Experimental work is required to establish sizing and implementation guidelines.
    b. **Sensors** for PEV monitoring, both for charging and discharging the PEV back into the grid, along with supporting regulations.
    c. **Controls** that allow the utility (in addition to the customer), under an agreed to contract, to start and stop charging the PEV.
    d. **Security** of communications to and from any PEV and/or charging station.
    e. **Modeling and Forecasting** to determine what will happen tomorrow in terms of electrical demand with the increase in PEV and other distributed energy resources.
    f. **Reduction in losses**. The losses that occur in changing electricity from Photovoltaic Cells on the roof to the grid, back to DC to go into the PEV.
    g. **Garaging PEV** - Research on where PEVs are likely to be garaged both during the day and at night.
    h. **Natural disasters -** Use of the PEV batteries to support electric needs during natural disasters.

- **Modeling tools** need to be expanded to allow them to support distribution grid modeling for short-term and long-term forecasting, both static and dynamic, as well as integration of demand response and Transactive energy into the PEV fleet (e.g., the DOE maintained Open Source GridLab-D).

Each of these technological and economic changes will impact both acceptance of the PEVs and amount of energy consumed by them. It is very important that standards and research keep pace with the real world technological changes in PEV and storage technology. It is also important to realize that economics and regulation will be the largest drivers in adoption rates and the investment in the grid to support PEV integration.

4. Asset Management Challenges and Options, Including the Implications and Importance of Aging Infrastructure

Virtually every crucial economic and social function depends on the secure, reliable operation of power and energy infrastructures. Energy, electric power, telecommunications, transportation and financial infrastructures are becoming interconnected, posing new challenges for their secure, reliable and efficient operation. All of these interdependent infrastructures are complex networks, geographically dispersed, non-linear and interacting both among themselves and with their human owners, operators and users.

Although the age of our power infrastructure – particularly underground city networks – is a major issue, it should not be viewed in isolation. Instead, the power industry's focus should be on a holistic asset management approach to address grid resilience. That focus should weigh the relative risks and economics of maintenance, repair and replacement or retirement for the infrastructure's various elements. This holistic approach requires viewing the utility fleet of capital equipment as critical strategic assets impacted by age and external forces, and possessing capabilities and characteristics that can be leveraged to improve reliability. Aging infrastructure will benefit from the use of condition-based monitoring and assessment tools. Grid hardening can address extreme weather-related impacts, as well as physical vulnerability and cyber security threats. And power system capabilities and characteristics can be managed to improve reliability metrics, such as SAIDI and SAIFI, as well as system-wide outages. Integrating a holistic asset management approach with rational spending and resource decisions should achieve optimal, cost-effective solutions. An additional aspect requiring new processes and tools is managing new Smart Grid assets such as advanced metering infrastructure (AMI) and intelligent electronic devices (IEDs).

Furthermore, recent growth in natural gas production has helped address energy needs but has added an additional layer of complexity in **managing the electrical grid due to interdependency between electrical and gas infrastructures.**

Optimal, cost-effective solutions for holistic asset management, in turn, depend on rational risk assessment and management. While it is impossible to predict when and where future events will occur, it is possible to identify the substations and lines in the system that, as a result of their location, configuration and electrical characteristics, pose the greatest risk for large-scale outages. These results can then be used to **tailor grid resiliency investments to focus on facilities with the greatest risk for future events.**

Thus, while macro-forces have the potential to impact the nation's power infrastructure, risk is dynamic, local, and specific. National policies that support holistic asset management will help, but achieving hardening and resiliency on the ground will be specific to a utility's customers' needs, its legacy systems, location and technology roadmap.

A dynamic risk landscape requires **annual updating to ensure the protection of pertinent assets**. How has the risk portfolio or the spectrum of risk changed? The variability of extreme weather events has increased. The power industry in the United States is just beginning to adapt to a wider spectrum of risk. It is noteworthy that both the number and frequency of annual, weather-caused, major outages have increased since the 1950s. Between the 1950s and 1980s, those outages were under 10-20 per year, accounting for less than 21% of root-causes of major outages. In the period 2008-2012, those outages increased to between 70 and 130 per year. In that five-year period, weather-related outages accounted for 66 percent of power disruptions, which affected up to 178 million customers (meters). This adaptation process continues as we implement strategies, technologies and practices that will harden the grid and improve restoration performance after a physical disturbance. The investments so far in advanced metering infrastructure and the coming wave of investment in distribution automation are but the beginning of a multi-decade, multi-billion-dollar effort to achieve an end-to-end, intelligent, secure, resilient and self-healing system.

A major weather–related event on the scale of Hurricane Sandy is likely to overwhelm the power infrastructure, at least temporarily. It is difficult to guarantee uninterrupted electric service under such circumstances. The U.S. power industry is just beginning to adapt to a wider spectrum of risk. Cost-effective investments to harden the grid and support resilience will vary by region, by utility, by the legacy equipment involved and even by the function and location of equipment within a utility’s service territory.

Even a single threat can have disparate impacts, requiring nuanced responses. In Sandy’s case, coastal areas were subject to storm surges and flooding, while inland, high winds and lashing rain produced the most damage. Improved hardening and resilience for distribution systems in those different environments would take different forms. **Underground substations along the coasts may have to be rebuilt on the surface, while it might be cost-effective to perform selective “undergrounding” for some overhead lines further inland.**

The one generalization we can make, however, is that the pursuit of an intelligent, self-healing grid with security built-in into the devices and deployed in a layered defense architecture, has some common characteristics that will make the grid highly reliable in most circumstances. Additional, location-specific steps based on rational risk assessments also can be taken by utilities and customers.

Recommendations

- Support **holistic, integrated approach** in simultaneously managing fleet of assets to best achieve optimal cost-effective solutions addressing the following: **Aging Infrastructure, Grid Hardening (including weather-related events, physical vulnerability, and cyber security) and System Capabilities** (including reliability improvements).
- **Urgently address managing new Smart Grid assets** such as advanced metering infrastructure (AMI) and intelligent electronic devices.
- Encourage utilities to investigate practical measures to shorten times to replace and commission equipment failures due to extreme events or other reasons.
- In the case of long-duration interruptions, all utilities should adopt improved measures to provide customers with a timely estimate of when power is to be restored.
- When extreme events occur it is important for post-event reviews to determine impacts and lessons learned for better management of future events.

Asset Management

- Infrastructure security requires a **new model for private sector-government relationships**. Overlapping and inconsistent roles and authorities hinder development of productive working relationships and operational measures.

- Perform **critical spares and gap analysis and implement spare equipment programs**. A detailed inventory is needed of critical equipment, the number and location of available spares and the level of interchangeability between sites and companies. Mechanisms need to be developed for stockpiling and manufacturing long lead-time equipment and for reimbursement to the stockpiling authority, be it private or government. Other approaches include standardizing equipment to reduce lead times and increase interchangeability. Utilities should continue working with industry and manufacturers to ensure that the protection of spares and all assets is carried out, that transportation of large equipment is feasible, and to expand on the existing self-healing transformer programs.
- Increased federal R&D for emerging technologies that may impact T&D grids, including new types of generation, new uses of electricity and energy storage, with an additional focus on deployment and integration of such technologies to improve the reliability, efficiency and management of the grids.
- Application of proactive widespread condition monitoring, integrating condition and operational data, has been shown to provide a benefit to real-time system operations, both in terms of asset use and cost-effective, planned replacement of assets.

Reliability, Security, Privacy, and Resilience

- Facilitate, encourage, or mandate that secure sensing, "defense in depth," fast reconfiguration and self-healing be **built into the infrastructure**.
- Continued effort on coordinated **regional planning of a more redundant and less vulnerable transmission grid**.
- Continue developing operational tools to more accurately **forecast the availability of natural gas supply** for generators and improve unit commitment decisions.
- Mandate consumer data **privacy and security for AMI system**s to provide protection against personal profiling, real-time remote surveillance, identity theft and home invasions, activity censorship and decisions based on inaccurate data.
- Support alternatives for utilities that wish to reduce or eliminate the use of wireless telecom networks and the public Internet where there might be concerns about increased grid vulnerabilities. These alternatives include the ability for utilities to obtain private spectrum at a reasonable cost.
- Improve **sharing of intelligence and threat information** and analysis to develop proactive protection strategies, including development of coordinated hierarchical threat coordination centers – at local, regional and national levels. This may require either more security clearances issued to electric sector individuals or treatment of some intelligence and threat information and analysis as sensitive business information, rather than as classified information. National Electric Sector Cybersecurity Organization Resource (NESCOR) clearing house for grid vulnerabilities is an example of intelligence sharing.
- Speed up the development and enforcement of **cyber security standards**, compliance requirements and their adoption. Facilitate and encourage design of security from the start and include it in standards.
- **Design communications and controls systems** for more limited failures through decentralized systems and for better EMP withstand capabilities

- Increase investment in the grid and in R&D areas that assure the security of the cyber infrastructure (algorithms, protocols, chip-level and application-level security).
- Following R&D could help reduce equipment and system vulnerability:
    - The design and maintenance of transmission lines to address vulnerability
    - Creating appropriate alarms from transducers used for line sag/temperature/etc.
    - Developing models and methods for contingency analysis and vulnerability system assessment

Markets and Policy

- Use the National Institute of Standards and Technology (NIST) Smart Grid Collaboration or the NARUC Smart Grid Collaborative as models to **bridge the jurisdictional gap** between the federal and the state regulatory organizations on issues such as technology upgrades and system security.
- More transparent, participatory and **collaborative discussion** among federal and state agencies, transmission and distribution asset owners, regional transmission operators (RTOs) and independent system operators (ISOs) and their members and supporting research is needed to improve these parties' understanding of mutual impacts, interactions and benefits that may be gained from these efforts.
- Continue working at a federal level on better **coordination of electricity and gas markets** to mitigate potential new reliability issues due to increasing reliance on gas generation; and update the wholesale market design to reflect the speed at which a generator can increase or decrease the amount of generation needed to complement variable resources.

5. Recommendations for Metrics for Addressing Smart Grid Issues, Including the Importance and Necessity of Protocols

The rapid changes in systems, technology, lifestyles, and policies have created both new opportunities and new expectation from the electric grid. Indeed, adding and using existing intelligence — sensors, communications, monitors, optimal controls and computers — to our electric grid with security built-in, can substantially improve its efficiency and reliability through increased situational awareness, reduced outage propagation and improved response to disturbances and disruptions. Smart Grid can also enable consumers to better manage their energy costs.

Because the opportunities are almost limitless and a broad array of functions is feasible, there are many differing expectations as to what will be facilitated by the Smart Grid. In absence of limitless funds, it is important to decide on the priorities and timing of various elements of the ultimate functionality, which in turn implies a need for a metric.

Any Smart Grid metric depends on the definition of the Smart Grid, specifically the performance requirements of the system. Conversely, it is difficult to derive a meaningful qualitative or quantitative metric without clear performance requirements.

IEEE uses the definition developed by the U.S. DOE's Modern Grid Initiative, which articulates seven key characteristics of a modern grid:

1. Enable active participation by consumers
2. Accommodate all generation and storage options
3. Enable new products, services, and markets
4. Provide power quality for the range of needs in a digital economy
5. Optimize asset utilization and operating efficiency
6. Anticipate and respond to system disturbances in a self-healing manner
7. Operate resiliently against physical and cyber-attack and natural disaster

IEEE has used these to develop a set of key drivers, which are the basis of the work IEEE is doing on establishing Smart Grid metrics.

It is important to acknowledge that there are other definitions and viewpoints, hence any metric used by the U.S. DOE may not meet the needs of others. A Smart Grid investment of high value to one party may not create much value to another party. Ultimately **the metric and any figure of merit will depend on the perspective and the framework of the stakeholder.**

Recommendations

Metrics & Priorities

- Metrics, and hence priorities for Smart Grid elements depend on viewpoint of the stakeholders. We recommend development of **two sets of metrics**
    i. One driven by electricity users' needs and preferences and
    ii. Another, driven by national, regional, and state priorities

  Such an effort should strive to secure support for these metrics by both federal and state regulators.
- As there are a number of various scorecards under development or in use, we also recommend that DOE support ongoing private sector development of metrics and combine the results into a **"super-metric"** that could be configured by users to reflect the stakeholder and regional needs.
- Increase emphasis on providing Smart Grid functions to the **commercial customer sector** (incl. small commercial).

Protocols and Interoperability

The Smart Grid cannot function without standardized, inter-operating protocols. In fact, availability of industry consensus standards is the key to successful implementation and long-term viability of Smart Systems.

- **Standards:** Work with IEEE's Standards Association, other Standards Developing Organizations (SDOs), and the stakeholder community to improve the timely development of Smart Grid standards, and promote their widespread deployment, including putting selected standard development on "fast-track".
- **Smart Grid Interoperability Panel:** Continue federal government support for the Smart Grid Interoperability Panel (SGIP) as the principal coordinator of Smart Grid standards under EISA 2007, to the extent needed to ensure the viability and continued operation of this evolving private-public partnership.
- **Testing and Product Certification:** Develop an institutional infrastructure for testing and certification of products claimed to be compliant with Smart Grid standards; and means for rapidly resolving technical issues and ambiguities, either prior to or immediately following, adoption by SDOs.
- **Broadband Communications:** Support the advancement and the deployment of broadband and other communication technologies that are essential for achievement of Smart Grid benefits.

6. Skilled Workforce Issues

The energy industry is undergoing a significant transition, described by some as a revolution. Driving this change are many technology breakthroughs aimed at addressing a growing and aging population, responding to customer needs, increasing environmental awareness and escalating response to cybersecurity needs. Advancements have been realized and are continuing to facilitate carbon management, electric transportation, sustainability and increased system reliability and flexibility. There are now more renewable generation and storage options coming, with the promise of increased ability to control and manage electric systems, and demand-side capabilities. Much of this progress has stemmed from market developments and a wide-range of technical advances in the areas such as electric machines, power electronics, batteries, photovoltaics, wind turbines, controls, communications, and embedded intelligence.

Workforce requirements and competencies are evolving to successfully innovate, plan, design, operate and maintain reliable, secure, and safe systems in the future. There is more uncertainty, advanced threats, increased complexity and a need to involve those with a wide variety of capabilities and backgrounds than ever before.

As new technologies come online, power may be generated and managed at new scales (at the home, local/distributed, and large-scale levels). The intersection of the power and transportation sectors will likely grow with increasing electrification of the auto fleet, and more individuals, small-businesses and private entities will play important roles in changing how people interact with the energy system on a daily basis. This will lead to a larger number of individuals, with a broader and diverse range of skills and interests interacting with the energy system and markets.

Workforce implications should not be viewed separately from research or policy review but as a key factor in the potential success of the action. Changes in the size, scope, location and competency levels of the energy workforce can have significant impact on the ability of the current workforce to advance the industry and implement the technological advances that will make our energy future cleaner and more reliable.

U.S. government can play a role as a convener of the key parties, both inside and outside of government. While many dimensions of workforce development may lie outside the main missions of DOE, there are real and significant opportunities to serve as the catalyst that brings information to other agencies and state/community/industry partnerships. As the economy is primed for recovery, energy technology jobs may well be a cornerstone of our economic growth across American cities.

The energy sector in the US is among the most robust and reliable in the world. Indeed, while there are many urgent needs and persistent cries for improvement, **the issues of aging workforce, aging equipment and new technologies plague Europe and developed countries all over the world**. The salient features of US markets that balance private and public assets with robust environmental and market regulations may well be America's most valuable export. In many countries across the world, not having this balance and equilibrium of regulation, markets, and public power make private investment too risky. We should celebrate what we have while seeking to improve it.

The strategy for workforce retention, keeping skills up-to-date and individual advancement is for any organization (including government agencies, utilities/RTOs, academia, private enterprise) to support participation of individuals in IEEE standards development, IEEE/CIGRE professional activities and conferences, and attending IEEE/CIGRE continuous education initiatives (e.g. tutorials). It is win-win for cross-pollination of ideas, sharing of best practices, balance in development of standards and documents.

Recommendations

- **Education Partnerships**: Governments and other stakeholders should support the development of partnerships within the education, labor, industry and government sectors, to develop new curricula and enhance secondary and post-secondary energy sector workforce training programs, apprenticeships and best practices.
  - Develop an educational road-map that aligns with industry needs.
  - Sponsor a study that effectively bundles the supply and demand assumptions, competency requirements, trends, risks, barriers and possible scenarios to be best prepared for the dynamic workforce needs.
  - States can develop and integrate recruitment, training, employment placement programs in concert with electric utilities and community colleges.
- **Certification Programs**: Universities and professional organizations (including IEEE) should create industry recognized credentials or certifications that can be awarded after the completion of education or training, to demonstrate an individual's achieved skill level.
- **Assess Workforce Issues**: Take necessary actions at the federal level to better understand the implications of a maturing workforce, technology advancements, and policy changes on future workforce requirements.
- **Develop Annual Recognition Programs** on excellence in the state of power system education and training. This program should seek out and celebrate excellence in private – public – educational institution partnerships.
- **Coordination and Communication**: Agencies at the federal and state levels and schools should leverage research, share programs / curriculum and track trends. For example, joint NSF and DOE efforts would ensure university research grants are optimally leveraged to impact workforce development.
- **Military Veterans Transition**: Identify and embrace best practices that effectively accelerate transition to meet industry workforce requirements.
- **Research or Policy Review**: Any review should include workforce implications (size, scope, location and competency levels) as key factors in the potential success of the action.
- **Industry Initiatives:** Participation of individuals in IEEE standards development, IEEE/CIGRE professional activities and conferences, and attending IEEE/CIGRE continuous education initiatives (e.g. tutorials)

Pertinent government agencies should aggressively support development of new curricula that add market economics to electrical engineering degrees. The recommendations illustrate ways that the DOE can establish priorities and partnerships, and take on a leadership role to ensure that adequate utility workers are recruited and trained to maintain a reliable electric system for today and for the future.

7. Report Cards on the Condition and Performance of the Electric Grid

The American Society of Civil Engineers (ASCE) does an annual report card on the infrastructure in the US. That report card focuses far more on age and subjective responses from members of ASCE than it does on the actual status of the infrastructure. The electric grid is lumped in with pipelines and other energy infrastructure. In 2013 ASCE assigned a grade of D+ to the energy infrastructure, primarily based on the age and replacement rate of assets which may not accurately reflect the status of the electrical infrastructure.

There is a need to create a survey that provides realistic status of the electrical infrastructure that allows rational decisions to be made on where to invest and what the impact of those investments are. There are several organizations that have pieces of an electrical survey, these instruments vary from heavily used to very lightly used. They also vary in the depth of coverage of their topics.

Existing Survey Tools and Missing Pieces

The North American Electric Reliability Corporation (NERC) does an annual report on the reliability of the transmission system that was mandated by the Energy Act of 2005. NERC has developed a deep and consistent methodology for the assessment of the transmission network.

Carnegie Mellon University (CMU) was given the Smart Grid Maturity Model (SGMM) by IBM. This tool assesses the information technology and operational technology (IT/OT) for a modern grid. This instrument does a wonderful job at assessing the IT/OT, communications systems, and the overall organizational design. It is light on field operations and the installation of equipment in the field.

The GridWise Architecture Council (GWAC) has developed the Smart Grid Interoperability Maturity Model (SGIMM) that covers the interfaces between IT/OT systems and the messaging that is sent between the systems. The tool also looks at the security of each of these individual interfaces. This is a detailed survey that can be run for every interface in the organization.

The Department of Energy (DOE) has its Electricity Subsector Cybersecurity Capability Maturity Model tool which provides a tool set for assessment of the cybersecurity.

The Nuclear Engineering Institute and the NRC both have survey tools for Nuclear Power Plants.

For Transmission, the survey tools developed by NERC are complete and should be considered as a pattern for other portions of the grid, such as generation and transmission.

In distribution the tools for CMU, DOE, and GWAC provide strong components to assess the intelligence of the grid and the adequacy of security, communications and information technology. What is missing and could be modeled from the NERC tools, are the installation of field equipment, substation status, failure rates, staffing levels and the other operational components of the distribution grid. The NERC model would need significant work to make it possible to complete the assessment with a reasonable effort.

In generation, FERC has in the Form-1 a large amount of the material needed to support an assessment of the adequacy of the generation fleet. There are operational and maintenance aspects that are not included in the Form-1. FERC Forms 714 and 715 provide some, but not all of this information and Form 556 provides information on smaller generation facilities. Again the existing FERC data would not provide a complete survey, but it is a strong starting point to develop survey results from.

For sales, forecasts, usage, and other consumption related information the U.S. Energy Information Administration (EIA) provides the best starting point.

Recommendations

The recommendations for a survey of the electrical infrastructure:

- Bring together the industry and end-user stakeholders to look at the existing survey tools, and define the overall needs for an industry wide set of survey tools. This working group should provide a clear requirements document on what needs to be surveyed, and the depth that the survey needs to cover.
- Determine what existing materials can be used to support the survey requirements, minimizing new data collection.
- Provide adequate resources to complete a survey tool set that supports the requirements that were developed by the stakeholder group and uses the data from existing sources.

Working with an industry working group, define how the survey tool will be used both improving the infrastructure and in any regulatory actions. The tool set will fail, if there is no consensus among the stakeholder groups. A solid survey tool set for both self-assessments will provide a data driven way for the industry to determine where to focus research, standards development, training, staffing, and operational improvements for the industry. With the rapid changes in the environment this will allow the better deployment of scarce resources.