Smart Grid Skills for the Energy Workforce

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Executive Summary

This report describes the experiences of individuals engaged in regional smart grid upgrade projects and identifies some of the key issues raised by interview respondents regarding technology implementation and workforce development. The study is supported by the Pacific Northwest Center of Excellence for Clean Energy (Centralia College) under a grant from the U.S. Department of Energy (DOE) aimed at supporting the development of a smart grid workforce.[1]

The report findings are intended to:

- Supplement the development and improvement of energy-sector education and training programs and
- Guide industry-education collaborations that support modernization of the electrical grid and development of the energy workforce across the Pacific Northwest region.

Although smart grid technologies are being implemented by many utility partners, the level of investment and depth of implementation vary considerably. It was determined that an effective approach to this research was to focus on three regional smart grid projects that were in an advanced stage of implementation, and to limit the inquiry to a small number of occupations of particular interest to the study sponsors and stakeholders. Primary methods included literature reviews, document analysis, and 17 interviews of utility project participants and smart grid experts.

Findings

Although grid modernization is aimed at technical innovations and upgrades that improve overall performance and system flexibility, the design and implementation of smart grid projects were subject to unique contextual and social conditions and forces that shaped how each project was planned and implemented. Some of the major factors emphasized by interview respondents are categorized within three broad, interdependent dimensions that effected change.

Environmental Factors

The award of federal funding to extend current work and initiate new smart grid projects was a mixed blessing. While the funds allowed project partners to accelerate existing modernization work and test new technologies and approaches, the award also created new expectations and aggressive timelines for staff and project work that was highly visible. “Drinking from a fire hose” was how one project manager described the experience. These projects typically extended or leveraged work that utility partners were already engaged in that was deemed necessary and an evolution of planned technical changes. However, some respondents noted that the complexity of the project elements, new technologies, staffing and the pace of project schedules represented more of a revolution than an evolution for utility organizations, and some employees struggled to support and adapt to these changes.

[1] Detailed information on the Smart Grid Workforce Training project can be found at: www.cleanenergyexcellence.org.

Contextual Factors

The importance of continuous coordination and team building among design and implementation partners—including vendors and consultants—was emphasized as critical for project success. Some of the risks associated with weak coordination and participation on schedules, workload and performance were described. The projects relied heavily on outside vendors and consultants for grid products and support for installation and integration, but the challenges of coordination and limited internal and external expertise sometimes caused delays and added workload for existing project staff.

Smart grid requires a high level of integration between IT, operations and communications technologies, but this requires employees to increase their knowledge about each of these technologies and processes to understand their effects across the entire organization. At the same time, each of these major systems is complex, and it is not practical or effective for employees to have both broad and deep knowledge in multiple areas.

Smart grid technologies have generally enhanced the safety of operations and maintenance personnel, but greater reliance on automation and remote control of grid operations sometimes increases the perceived risks to front-line employees. Strategies that reaffirm safety procedures and promote team building help to build trust.

Knowledge-Foundational Factors

Smart grid systems and technologies are complex and interdependent. Employees at all levels need to understand how these systems work together and impact their work and the organization. Employees who have a broad knowledge of different subject matter and the ability to relate that knowledge and experience to their work are valued and desirable in a smart grid environment. Specialists with deep subject knowledge continue to be important, but the ability to draw from many disciplines and experiences enables employees to grasp the complexities of the many facets of grid modernization and to contribute in unique ways.

Respondents suggested that existing power engineering education and training programs should be reviewed and upgraded to include or expand their emphasis in several technical and non-technical areas. Greater knowledge and skill was suggested for computer and software programming, data analysis and management, customer database structures, and distribution automation. Non-technical areas included project management and coordination, and educating and serving customers.

The key knowledge and skill areas identified by respondents pertain primarily to engineering, technical operations, and customer service/support occupations. These are areas that should guide the review, development or improvement of university, two-year college, apprenticeship, and other education and training programs so they are responsive to the needs of employers and the workforce in a smart grid environment.

Conclusions

Smart grid modernization projects represent complex socio-technical system changes that require new technical and non-technical knowledge, and a high degree of interdependence among employees at all levels. For many employees, this means acquiring greater technical knowledge and skill, but also greater understanding of systems and integration, cross-disciplinary knowledge, teamwork and team-building, project management, and other foundational workplace skills that support project and organizational success, and which equip and enable employees to function effectively in a smart grid environment.

Introduction

Smart Grid technologies are changing how utilities generate, transmit and distribute electrical power. While there are many definitions, smart grid, simply put, denotes a set of technologies that can be used to upgrade the current electrical grid (NIST, 2012).[2] These technologies are shifting how the industry interacts with and manages our nation's complex energy system, while providing new opportunities for consumer engagement.

The promise of smart grid is that the use of enhanced technical devices and the integration of computerized systems and digital information will spur improvements in the reliability, security and efficiency of the existing electrical grid. Technology-driven bidirectional flows of energy and data will enable enhanced communications and control capabilities, and improved integration of distributed resources and power generation, including renewables. Smart grid technologies will also expand the infrastructure and charging capacity for electric vehicles, and promote greater energy efficiency through the use of "smart" appliances and other energy-efficient consumer devices, and by identifying wasteful or unnecessary electrical consumption. This two-way, nearly real-time exchange of information will also enable enhancements in grid security, and will allow consumers greater access to their own energy usage information, enhancing their ability to engage directly in decisions about energy use and control options.

The application of smart grid technologies is not new: Devices such as automated metering and enhanced control systems have been installed and used by utilities for many years. However, the implementation of these technologies has not been consistent; utilities are also tasked with evaluating the cost-benefit of new technology enhancements. In many circumstances, low cost-benefit estimates have rendered the application of smart grid technologies across the industry to be limited and uneven. More recently, the scope and potential complexity of many smart grid technologies and projects have increased, which has also delayed implementation by some utilities.

Despite these challenges, continued technology advances, public and private-sector interest, and consumer demand have driven up investments in clean energy markets, leading to new or enhanced smart grid products and applications that show great promise. Substantial federal investments in grid upgrades have been made, and the provision of recession-era funding under the American Recovery and Reinvestment Act (ARRA) of 2009 have supported the development of new projects, including several demonstration projects by consortia partners in the Pacific Northwest region.[3]

Upgrading the Electrical Grid with Smart Grid Technologies

It is important to recognize that the U.S. electrical grid as it currently exists is already quite "smart." Indeed, the grid is widely regarded as one of the great technological and engineering marvels of our time. The basic design by Tesla in the late 1800s is still in use today, delivering reliable electrical power produced by thousands of generation stations across the country, which together supply over 950,000 megawatts of generating

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[2] National Institute of Standards and Technology, 2012: http://www.nist.gov/smartgrid/.

[3] For a description of DOE-funded smart grid projects in the Pacific Northwest region, see: http://www.pnwsmartgrid.org/. See also: http://smartgrid.ieee.org/june-2012/601-largest-u-s-smart-grid-demo-project-is-set-to-roll.

capacity.[4] These generators produce alternating current electricity that is synchronized at the point of production to the exact frequency of the entire grid, comprising a continuously operating, interconnected system of generation, transmission and distribution infrastructure that is arguably the largest and most complex machine in the world.[5]

Why upgrade the grid?

There are a number of reasons why upgrades to the electrical grid are needed, not the least of which is that the existing grid, while having served its intended purpose well, is worn out and will require replacement of its major physical systems. The massive 2003 blackout in the Northeastern U.S., in which 50 million customers lost power and economic losses were in the billions, revealed the fragility of the grid and a need for better monitoring and disruption control. At the same time, concerns about the causes of climate change have grown, and electricity generation is the single largest contributor of greenhouse gases in the U.S.[6]

Efforts to shift to renewable sources of generation, for all their known environmental benefits, will require upgrades to the entire electrical grid. These upgrades will provide the greater flexibility needed to achieve high levels of penetration by renewables. And, while the new technologies enabling the networking and digitizing of the electric infrastructure can lead to advances in efficiency and reliability, they also reveal the need for higher levels of cyber-security to reduce system vulnerabilities.[7] Finally, achieving greater grid efficiencies, enabling the electrification of our transportation system, and providing a way to dynamically adjust electricity pricing to compel consumers to reduce costs and help balance supply and demand, will require a more robust communications network than is currently in place.

"Smart grid" is commonly associated with smart meters, which are part of an Advanced Metering Infrastructure (AMI) that enables automated, two-way communications between a customer's meter and the utility. The goal of AMI is to provide utility companies with real-time data about power consumption and allow customers to make informed choices about energy usage based on the price at the time of use. But meters are just one of many enabling technologies which, when combined, will support a more intelligent and efficient power system.

The National Energy Technology Laboratory identified five major categories of smart grid components.[8] They include:

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[4] For a brief history of the U.S. electrical grid and system operation, see Appendix A.

[5] NAE (National Academy of Engineering). 2003. Greatest Engineering Achievements of the 20th Century. Available online at http://www.greatachievements.org/.

[6] U.S. Environmental Protection Agency, 2012. See: http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

[7] Amin, S.M (2010) *Securing the electricity grid*. National Academy of Engineering, The Bridge (Spring) 13-20, http://www.nae.edu/File.aspx?id=18585. Also: *Renewable Electricity Futures Study*, 2012 (June). National Renewable Energy Laboratory. http://www.nrel.gov/analysis/re_futures.

[8] *A Systems View of the Modern Grid*. National Energy Technology Laboratory Office of Electricity Delivery and Energy Reliability: http://www.netl.doe.gov/smartgrid/referenceshelf/whitepapers/ASystemsViewoftheModernGrid_Final_v2_0.pdf. For a brief summary of major smart grid components, see Appendix A.

1. **Advanced Transmission and Distribution Components**: Transmission and distribution components rely upon innovative power electronics and superconductive materials to manage the transmission and distribution of electricity.
2. **Advanced Controls**: Physical devices and intelligent software tools that will analyze, diagnose, and predict conditions in the modern grid and take "self-healing" corrective actions.
3. **Sensing and Measurement Equipment**: Advanced sensing and measurement devices such as AMI and Phasor Measurement Units (PMUs) that use global positioning satellite technology to take time-synchronized measurements to monitor the status of the grid.
4. **Improved Interfaces and Digital Support**: Advanced interfaces that improve the human system operator's ability to quickly analyze large amounts of digital data and respond to grid events.
5. **Integrated Communications**: Smart grid technologies must be built on a fast, reliable and secure communications network, which allows for "plug and play" integration of new technologies, tools and communications methodologies as they are developed.

Workforce Impacts

Although the development and application of smart grid technology will alter the electric power industry and provide new opportunities for consumers to engage, grid upgrades are also expected to impact the work of utility employees, who at the very least must learn about how to integrate, install and maintain these new technologies. For instance, the installation of advanced metering and communications devices is expected to vastly increase the volume and frequency of information available to utilities to use to monitor and improve system performance.

The alignment or overlay of information systems with operations technologies has enabled the collection and management of large amounts of complex information ("big data") that requires specialized data management and analysis expertise that most utilities currently lack. This Information Systems/Operations Technology skills gap is predicted to continue and even worsen because, in addition to electric power, there has been a rapid expansion in the capabilities and value associated with the collection, analysis and use of large data bases for business strategy and decision-making in virtually every industry sector in the economy.[9] Moreover, the competitive advantages now associated with the ability to mine big data is expected to be constrained by a lack of talent by individuals with skills in statistics, machine learning, data management, analysis and interpretation. One report projects a 50% to 60% gap will exist between the supply and demand for highly skilled analytical talent in the U.S. between 2008 and 2018 – a difference of up to 190,000 positions. The report further estimates that there will be a need to add 1.5 million additional managers and analysts in the U.S. with proficiency in the analysis and effective use of big data results.[10]

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[9] *Big data: The next frontier for innovation, competition, and productivity*. McKinsey Global Institute, 2011: http://www.mckinsey.com/insights/business_technology/big_data_the_next_frontier_for_innovation.
[10] *Big data:* McKinsey Global Institute, 2011.

Whether the job of data management and analysis should remain a centralized function or be expected of many more utility employees remains to be determined, but the example underscores how markedly technology innovations can shift the requirements for specific types of employee knowledge and skill.

Looking more broadly, the extent to which smart grid implementation requires new knowledge and skills across a range of energy occupations is also unclear; existing research is mixed on this issue, and the impacts may vary by technology and type of occupation. Some reports suggest that while smart grid technologies will indeed alter the utility-customer relationship, the core work of most employees – especially craft workers such as line workers, technicians, electricians and mechanics – is likely to remain the same.[11] Other reports point to the need for higher-level knowledge and skills development in a smart grid work environment, especially among professional employees such as engineers and technical managers.[12]

Moreover, the existing literature and information gathered for this report suggest that, beyond the development and implementation of new technologies and systems, smart grid modernization efforts comprise complicated systems changes that affect the entire utility organization and its employees.[13] In fact, much of the existing smart grid-related research and public discussions tend to focus on specific technical solutions and their economic potential without regard to broader social or cultural effects.[14]

Some researchers stress that grid upgrades should be considered in a broader, interdependent context that encompasses social and technical change, because electricity systems are socio-technical systems.[15] Others argue that while the social, behavioral and institutional dynamics accompanying smart grid technological shifts have received less attention, they are critical for both electric system function and meeting other objectives, such as reducing the impacts on climate change.[16]

Finally, some researchers caution that failure to recognize smart grid modernization as sociotechnical phenomena may generate resistance and even a backlash from the many stakeholders (in addition to consumers) that smart grid changes are intended to serve. Employees, for instance, are critical to the successful implementation of smart grid upgrades, which makes it important to evaluate the associated changes for their effects on employees' work and company expectations. As one McKinsey report noted: "…Unless the impact on front-line employees is handled intelligently, the expected operational benefits may

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[11] *The Smart Grid Evolution: Impact on Skilled Utility Technician Positions*. Center for Energy Workforce Development (undated): www.cewd.org.

[12] Heydt, G., Bose, A. & Jewell, W., et. al (2009). *Professional resources to implement the 'smart grid'*. Institute of Electrical and Electronics Engineers, paper presented at the North American Power Symposium (October). Also: *Preparing the U.S. Foundation for Future Electric Energy Systems: A Strong Power and Energy Engineering Workforce*, U.S. Power and Energy Engineering Workforce Collaborative, Power & Energy Society, the Institute of Electrical and Electronics Engineers, 2009. See: http://www.ieee-pes.org/images/pdf/US_Power_&_Energy_Collaborative_Action_Plan_April_2009_Adobe72.pdf.

[13] Stephans, J., et al. (2013). Getting Smart? Climate Change and the Electric Grid. *Challenges* **2013**, *4*(2), 201-216; doi:10.3390/challe4020201.

[14] Giordano, V.; Fulli, G. A business case for smart grid technologies: A systemic perspective. *Energy Policy* **2012**, *40*, 252–259.

[15] Verbong, G.; Geels, F. Future Electricity Systems: Visions, Scenario's and Transition. In *Governing the Energy Transition: Reality, Illusion or Necessity?* Verbong, G., Loorbach, D., Eds.; Routledge: London, UK, 2012; pp. 400–434.

[16] Kostyk, T.; Herkert, J. Societal implications of the emerging smart grid. *Commun. ACM* **2012**, *55*, 34–36.

not materialize."[17] Utility organizations are often described as conservative, risk-aversive bureaucracies that can be very resistant to changes that alter existing technical structures as well as financial and social relationships; however, those that are able to establish support for changes based on common goals, teamwork and trust are often able to perform more effectively.[18]

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[17] Can the smart grid live up to its expectations? McKinsey & Company, 2010. See: http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/mckinsey_on_smart_grid

[18] Mayfield, R. (2008). *Organizational culture and knowledge management in the electric power generation industry*. Doctoral dissertation, University of Phoenix (October). *SAS Utility Industry Survey: How Utilities View Analytics* (2012). SAS Global Product Marketing, Energy and Sustainability: www.sas.com/utilities. Also: Petty, M., Beadles II, N., Chapman, D., Lowery, C. and D. Connell, (1995). *Relationships between organizational culture and organizational performance,*" Psychological Reports 76: 483-492.

Methodology

This study sought to answer two basic research questions:

1. What is the impact of smart grid technology implementation on the knowledge, skill and ability requirements of energy employees in select occupations?
2. What are some of the major implications for education and training of current employees and new hires?

An initial review of available literature on smart grid technologies was conducted. In addition, available research on the relationship between smart grid technologies on the work and skill needs of energy employees was reviewed. Additional research for specific occupations was incorporated into the report, as noted. A standard interview protocol was established based on the project goals and a review of available research literature and relevant industry reports.

Study Sites

Pre-project conversations with several utility representatives revealed that their limited experience in developing or installing smart grid technologies precluded them from providing experience-based responses to these questions. Thus, it was determined that the richest source of current information was from individuals and utility-scale projects that were at an advanced state of selecting and implementing smart grid technologies. The primary data was collected through telephone interviews of 17 individuals from regional energy organizations that are leading or contributing to recognized smart grid demonstration projects in the Pacific Northwest, including Avista Corporation (Washington), Flathead Electric Cooperative (Montana), the Pacific Northwest National Laboratory (Washington), and the Bonneville Power Administration (Oregon).

Occupations of Interest

The choice of occupational groups was based on results of the literature reviews, stakeholder interest and prior work conducted for the Smart Grid Workforce Training project. Time and resource constraints precluded extensive additional data collection for other occupational groups. The primary occupations of interest represented three areas:

1. Engineering (power engineering)
2. Technicians (line workers and metering)
3. Customer service (customer service representatives)

Each telephone interview lasted between 30 and 90 minutes, and several follow-up phone calls were conducted to collect additional information or to clarify specific points. All respondents were assured confidentiality, and all data is reported in aggregate form.

Demonstration Sites and Descriptions

The Pacific Northwest region currently hosts the largest of 16 national smart grid demonstration projects in the U.S., funded in 2010 by the DOE under the American Recovery & Reinvestment Act (ARRA).[19] Among this

[19] For a description of DOE-funded smart grid projects in the region, see: http://www.pnwsmartgrid.org/. See also: http://smartgrid.ieee.org/june-2012/601-largest-u-s-smart-grid-demo-project-is-set-to-roll

suite of projects in five Northwest states, some are small in size, with the scope limited to the installing and monitoring a small number of smart grid components, such as smart meters. Others projects are truly regional in scope and incorporate an entire portfolio of technology tools, components and targeted systems changes.

Project/Site Summaries

Detailed descriptions of the overarching regional smart grid demonstration projects can be found at www.pnwsmartgrid.org. This report includes input from a limited number of smart grid experts regarding the regional smart grid initiative.

The Pacific Northwest Smart Grid Demonstration Project (PNW-SGDP)

The PNW-SGDP is a collaborative, five-year test of new technologies and capabilities that are intended to upgrade the region's power grid. Unique in size and scope, the PNW-SGDP project is managed by Battelle's Pacific Northwest Division located in Richland, WA, and involves the Bonneville Power Administration, five technology partners, and 11 utilities across five states: Washington, Oregon, Idaho, Montana and Wyoming. The PNW-SGDP will demonstrate the potential for a safe, scalable and interoperable smart grid for regulated and non-regulated utility environments. Each of the individual demonstration projects operating in the region, including Avista/Pullman demonstration and Flathead Electric Cooperative projects (described below), operate under the PNW-SGDP umbrella.

Avista Utilities, Spokane WA

Avista's Smart Circuits project is upgrading electric facilities in the Spokane area with the help of federal stimulus funding through its Smart Grid Investment grant. In 2010, the DOE awarded Avista $20 million in investment grant funds – the largest matching smart grid investment grant in Washington. Avista is contributing $22 million for a total planned project investment of $42 million. The funding allows Avista to accelerate the pace of planned upgrades and deploy a distribution management system, intelligent end devices and a communications system that will affect more than 110,000 electric customers in Spokane. The project is intended to reduce energy losses, lower system costs, and improve reliability and efficiency in the electricity distribution system. Customers should see fewer and shorter outages.
http://www.avistautilities.com/inside/resources/smartgrid/smartcircuits/Pages/default.aspx

Avista Utilities, Pullman, WA

Avista joined with regional partners, led by Battelle, to develop a Smart Grid Demonstration Project using matching stimulus monies from DOE. The intent is to show how smart grid technology can enhance the safety, reliability and efficiency of energy delivery on a regional and national level. As a result of this project, the city of Pullman became the region's first smart grid community. The project involves automation of many parts of the electric distribution system using advanced metering technology, enhanced communication and other elements of smart grid. The project also integrates smart grid concepts developed by WSU Facilities Services in partnership with Avista to make WSU Pullman a smart grid campus. The WSU College of Engineering and Architecture is providing analysis and reporting of results for the project. http://www.avistautilities.com/inside/resources/smartgrid/pullman/pages/default.aspx

Flathead Electric Cooperative (FEC), Kalispell, MT

Established in 1937, Flathead Electric Cooperative, Inc., or FEC, is a locally owned and operated cooperative serving 48,000 members. FEC is now the second largest electric utility in Montana, with 3,900 miles of line serving the entire Flathead Valley and Libby, along with several hundred members along the Montana-Wyoming border. FEC's "Peak Time" project will focus on 300 volunteer households in the Libby area and 150 in the Marion and Kila areas. Volunteer participants will be eligible for free in-home displays, peak time usage rebates, appliance incentives and the opportunity to deploy their own home energy network. This will not only demonstrate the coordination of modern grid assets using innovative communication and control systems, but also help the Co-op determine the most cost-effective ways to reduce power supply costs during time of high demand. http://www.flatheadelectric.com/energy/peak/index.php

Findings

Study findings integrate the primary themes and topics identified by respondents as important to the design and implementation of smart grid projects. The overall environment for smart grid project development, the context for implementation, and identification of important knowledge and foundational skills are included. The findings focus specifically on topics emphasized and verified by the majority of respondents as important to project development and implementation; not all topic areas introduced by respondents are included, nor do they represent a comprehensive review of workforce development issues tied to individual projects.

Federal Funding: Opportunity and Expectation

Several respondents described the award of federal ARRA grant funds as a mixed blessing. On the one hand, receipt of the new funds enabled them to both accelerate modernization work they had already planned or begun, and to launch new project elements or enhancements that were more comprehensive. Most respondents said they were positive about the opportunities that the federal investment enabled, and several noted that the resources and new expectations created new pressure for action that ultimately resulted in greater cooperation and teamwork internally and with external stakeholders. One manager noted: “When we got the ARRA (stimulus) grant, we spent a lot of time figuring out how to do what we wanted to do, getting everything ironed out, from vendors and specific systems we needed, to project planning and work flow.”

On the other hand, several respondents reported that the receipt of federal funding brought with it added pressure and tight timelines, concerns about staffing project work, and high visibility and increased expectations among top management about achieving results. One manager described the experience as akin to “drinking from a fire hose.” Indeed, some of the most oft-cited challenges to project development and implementation noted by respondents across the demonstration projects were tied in some way to the impact of federal project funding. One technical manager noted:

> The way the ARRA grants rolled out, it was rush to submit your application and then wait, then rush to make a ton of decisions because there’s 3.4 billion dollars pouring into the economy with very few vendors available. We know if we’re not behind the eight ball we’re going to be months if not years out on getting the material we need. So we immediately, with as much impetus as possible, made decisions on the types, quantity and location of devices and we cut purchase orders. We almost immediately started receiving these devices. As a utility we were looking at this monumental project, installing more switches and re-conduiting more overhead power lines, strictly with internal resources, in under three years, than we would normally do in six to ten years. So because of that time constraint and the emphasis put both by the DOE as well as internally, it was a huge emphasis on ‘let’s go out and get it done.’ So we jumped in with both feet.

With existing staffs already engaged in current modernization work, some organizations recruited and hired additional employees to take on the added workload, and the expectations about involvement among current employees in new project work increased. Many respondents noted that the increased workload on existing staff was especially difficult during startup and the early phase of implementation but that, as the project progressed, the inclusion of additional project staff made their workloads more manageable.

Revolution vs. Evolution

Responses regarding the overall impact of grid modernization on their organizations ranged from revolution to evolution. Most organizations had already gained experience implementing smart grid devices such as automated metering and other technical improvements, and many of the technologies used in the grid modernization projects included common "off the shelf" components and systems that are also used in other industries. The addition of new project work was viewed by many as a natural evolution of necessary grid upgrades for the industry. Some respondents pointed out, however, that the adoption and integration of various software, hardware and control systems within the utility industry has generally lagged behind industry sectors like manufacturing, transportation and business information systems.

Employees who were directly tied to project design and implementation often emphasized that, at times, the scope and pace of the changes they were implementing did appear overwhelming, and the technology and process changes felt revolutionary. The pressure to launch the projects sometimes contributed to internal resistance. While over time there was greater acceptance among employees, some respondents—both senior and less-senior employees—described the "culture" of utility organizations as rigid, risk-averse and conservative, which sometimes delayed acceptance and contributed to some of the internal resistance expressed by employees. As one engineering manager noted, "It (smart grid modernization) is definitely a revolution for utilities. It's good for the industry, it brings different skill sets and people into the industry who are more excited about change, and maybe more adaptable to change."

Coordination: Technical and Social

The input provided by many respondents affirmed that nearly all phases of the smart grid modernization undertaken and completed by project leaders and stakeholders had required an intense and continuous emphasis on coordination and team-building among various design and implementation partners throughout their organizations and externally. While grid modernization clearly includes new technologies, system upgrades and technical expertise, it also requires high levels of coordination among many stakeholders, departments and functions, external vendors, suppliers, and consultants, such as:

- Equipment vendors who provide the physical infrastructure, components, software and technical consulting;
- Management and engineering staffs who establish the overall design specifications, technical requirements and integration plan for each project element;
- Technical staff who provide data, information technology and application support;
- Technicians, craft workers and other operations staffs who install, test/troubleshoot and repair system components;
- Project and administrative support managers; and
- Customer service staff who educate and support affected utility customers, who will have expanded control and decision-making capabilities.

Further, none of the organizations had fully implemented their project plans at the time of data collection. (Most were still installing or testing equipment, preparing customers, or otherwise implementing aspects of their projects; none were at the point of collecting or analyzing data on customers' energy use, behaviors or communication/tool use.) Most respondents reported that, while the network of relationships among departments, personnel and other stakeholders took time to develop and strengthen, these relationships and the teamwork that resulted had been critical to the successful implementation of the projects thus far. Most respondents reported that future project phases would also require considerable investments of time and resources to ensure relationship-building and effective coordination among implementation stakeholders.

It seems logical to expect that coordination would surface as a potential issue with smart grid project implementation; coordination and team-building among stakeholders are typically central to the success of any modernization effort. What stands out, however, is that respondents' comments about the importance of coordination were both frequent and emphatic. Indeed, the interview data collected from utility project staff and other regional smart grid experts suggests that these projects have been especially intense, and that they have each posed unique and sometimes formidable coordination challenges that extend beyond the technical/technology realms. Several respondents commented on the risk of not coordinating and including key partners in project discussions and decision-making. One engineering manager noted:

> Staff from different departments involved in the project need to be brought in during the design phase. Grid modernization is not just an engineering problem. For example, the decision to collect and bundle (customers' energy usage) data in five-minute or 15-minute intervals has a major impact on the information technology process. Here, that decision was made initially by engineers, who only discovered the challenges it posed to IT later in the project.

Vendors and Technologies

Stakeholder coordination with technology and equipment vendors was also a central issue raised by respondents. Grid modernization requires the development and acquisition of new technical equipment from external equipment vendors and other suppliers. Many of the technical systems were already available, but integration was described as very challenging. Project leaders did extensive planning to coordinate the design requirements with available technologies. Prior experience with equipment vendors and a growing familiarity with the capabilities of new smart grid components due to existing upgrade work helped ensure that the products and support provided by vendors met project requirements. In some instances, technical staffs met with staff from other utilities to learn from their experiences with similar grid modernization projects, vendors and components.

Consultants and vendors were typically engaged to support the design of various system components, to ensure functionality, and to help project leaders clarify equipment and performance requirements. But, many respondents noted that few vendors have all aspects of the broader system requested by utilities. While most equipment vendors are steeped in the capabilities and features of their own products, few have the "big picture" of system integration, which is complex. Several respondents described how project leaders, typically led by a team of engineering and management staff, conceived of the initial project technical specifications with input from vendors. Depending on the overall system design and internal expertise, consultants were sometimes engaged to assist in design and systems integration. As one smart grid systems expert noted:

> It's important to realize that most utilities are not doing much smart grid technology implementation themselves, mostly its subcontractors and vendors who are doing it—most of the

> utilities are not leading that work, in part because there's little in-house capability. A few utilities are doing some of the work, but overall, utilities are relying on contractors to do this work.

Some respondents noted that project schedules created considerable pressure to select equipment vendors and products quickly so that implementation could proceed without delay. In some cases, internal staff lacked the expertise needed to judge whether vendor products met the design or integration requirements; in other cases, consultants or even the vendors themselves were unavailable or lacked the expertise needed to verify or integrate the equipment. The lack of internal or external expertise sometimes forced existing staff to get up to speed quickly themselves, investing time and energy researching vendor products and specifications to ensure the integrity of the design and systems integration. One engineering manager noted that, at the time, this knowledge gap seemed unavoidable and even provided a professional development opportunity. But it also increased the workload for existing employees, and may not have been an efficient use of staff time:

> We didn't use a lot of consultants initially, it had been pretty minimal. For our DMS (distribution management system) we used (vendor name), but haven't had any consultants assist with integration or installation.[20] That's been true for most of what we've done. In contrast, now we're using consultants a lot for install of our new asset management system and customer service system, and to see that model and to see what we did with smart grid is like a night and day difference, because with smart grid we did it all ourselves. In retrospect we would have benefitted from using more consulting expertise with systems integration and installation. Part of the challenge was it was all just so new, there weren't a lot of people with the experience available to get us up and running, but now there is more experience out there so we would definitely use consultants more if we were to do it over. At first we didn't really know what we needed, so we had to figure it out on our own.

Adding to the complexity, at the time when some equipment purchases were being decided, some vendors were still testing or upgrading their products, while others were about to release new products that added greater functionality or performance. Some vendor products were truly "off the shelf" and available, but some others were still being refined or were not field-ready. One manager noted:

> We were lucky we had already gone through vendor reviews, but we did have to make decisions where we couldn't wait. Some vendors would say 'we'll have something better in a few months' but that's not always true, and in my experience it usually takes a lot longer than they estimate. And, we needed to move.

[20] DMS is a collection of applications designed to monitor & control the entire electricity distribution network efficiently and reliably. It acts as a decision support system to assist the control room and field operating personnel with the monitoring and control of the electric distribution system. Improving the reliability and quality of service in terms of reducing outages, minimizing outage time, maintaining acceptable frequency and voltage levels are key deliverables of a DMS.

In a few cases, respondents said that internal pressure to maintain aggressive project milestones rushed the selection of vendors and product components that caused problems later. One manager noted: “The grant process drives the timeline, and some analysis gets compromised.”

In the most extreme cases, staff sometimes had to push vendors and manufacturers to meet their own timelines, which strained the relationship and created tension. In other cases, engineering staffs had to conduct some of the analysis themselves, which added to their existing workloads. Some reported that the pressure to move forward led to the selection of products that were later found to be sub-optimal for the project. Several respondents reported that the pressure to move quickly resulted in some decisions about equipment purchases that were not effectively vetted with operations staff, which could have prevented problems later. On one project, for instance, an operations manager noted that some of the electrical distribution switchgear they purchased initially was found to be less accurate than another design option.[21] He noted:

> There were definitely decisions made without the input of operations that had a huge impact. Unfortunately the switch that we bought, in retrospect, was not a good decision. It fulfilled all of the immediate needs of what we needed the device to do. There were problems with installation from an operational construction perspective, but it was probably a year later when the relay techs started running commissioning that they really started to understand the impact of the lower quality metering. Then once we actually had entire feeders up and online and being monitored is when we truly understood the ramifications. But by that time we already had signed contracts, purchase orders were cut; there was no way to back out of it.

While this project team eventually found ways to improve functionality, the example underscores the importance of broad input from project partners and knowledge of vendor products. One industry expert noted that most vendors have a vested interest in promoting their own products and services, which can sometimes come at the expense of the clients they serve. When organizations tasked with implementing major grid upgrades lack the internal knowledge and expertise about system components, integration and functionality, it can put the project at risk. He noted:

> If utilities don’t have the internal talent to know about these technologies and how they should work, they can’t really monitor their (vendor’s) work or be sure if the contractors are delivering. We have some contractors out there who are overpromising and under-delivering, and that problem could be mitigated if utilities had the talent and knowledge to know.

He added that another reason it is important for utilities to have well-developed internal knowledge about vendor products is that most vendors offer only part of what is needed – few deliver the entire package of components, and so they often lack the full range of expertise needed to support component and systems integration.

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[21] Switchgear is the combination of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream. This type of equipment is important because it is directly linked to the reliability of the electricity supply.

Interdependence: Information Technologies and Operations

Smart grid is often described as an overlay of information and communications technology with operations technology. This overly simplistic description does hint at a fundamental feature of smart grid modernization: a high level of interdependence is required between information and communications systems, operations technologies, and processes. This design feature extends across transmission and distribution systems and components, and can range from:

- Equipment designed to measure the state of the power transmission and distribution system;
- The application of digital information systems that enable nearly real-time transfers of information that can be used to anticipate, prevent or respond to grid events;
- Enabling and integrating back-office systems such as billing or customer service; and
- Providing customers with current data on their energy use data and control options

All of these technical systems and processes depend on data and communications systems that are highly integrated and interdependent. As one smart grid project manager noted:

> Smart grid is all about systems integration and interoperability. Going forward, utilities need to be better able to work with systems interfacing. Whether they do it themselves or with contractors or vendors, they have to understand the requirements of these systems and the standards."

Traditionally, most back-office (administrative/business) information technology (IT) functions and departments developed separately from engineering and operations technologies (OT), with relatively little crossover occurring. But achieving smart grid goals has forced closer coordination and integration among IT and OT. As one smart grid systems expert noted:

> Data and communications systems have to be in place for these projects to work. So, you have project engineers working on the power engineering side of things, interacting in a much closer way with IT systems and staffs. In the past the IT folks were just managing back-office administrative systems. But now, those IT systems are central to the technologies and capabilities we're trying to implement."

One network engineering manager added that this shift also drives a need for employees at all levels to develop a broader understanding about the impact of these technologies on the business side of the organization, and how their own actions affect business processes, not just operations. "As operational technologies become more 'back-office' in look and feel, front-line workers for those need to be educated and tied into business processes…they need to know what the impact of their work is on business processes."

Respondents noted that in the best cases, project designers and managers actively brought IT staff into smart grid design conversations early, soliciting their input and expertise about IT capabilities in order to anticipate potential problems and to ensure that system integration efforts were designed for success. But, on some occasions – either due to the pressure to move quickly or because of the cultural silos that existed between engineering, IT and OT groups – communications and planning discussions between departments sometimes did not occur in a timely fashion or were inadequate. Several respondents indicated that a central challenge to better integration of information/communications technologies and operations has been the lack of knowledge between groups about their respective work, the content of which can be technically complex. One engineering manager noted:

> IT and operations technology integration, more of that is needed. There's lots of attention on that topic. Here, our SCADA system has traditionally been on the operational side of the business.[22] Now, with our distribution SCADA system we're putting in, we're crossing over to figure out roles between the two. Defining roles is a challenge, figuring out how to connect the two, and the gray areas between them. There's concern that enterprise technology doesn't have enough background in electrical engineering and power to understand technical systems – reliability, flow of our system, what affects reliability – so we're trying to keep those aspects on the operational side, but we also need our operations people to understand the software and programming, how the system works, so they can work with the enterprise technology side so they can help troubleshoot, and understand the problems.

Roles and Expectations

Several respondents noted that one of the challenges of integrating IT and OT has been defining roles and expectations of project departments and team members. Some respondents said the task of aligning and integrating IT with OT was conceptually and technically challenging, and that, in many cases, project staff were learning themselves what steps were needed, which required learning about the functions and capabilities of systems they were not very familiar with. One respondent noted how some engineers assigned to the project took it upon themselves to learn more about information technology, data structures, software and applications that were traditionally the purview of IT staff. Conversely, some IT employees worked to learn more about OT in order to understand those functions and to guide decisions about integrating the two systems.

While this cross-training was deemed important and valuable, some respondents questioned how much overlap was needed. Several respondents described cases where individuals went much deeper into learning IT functions and system management than originally envisioned. A few respondents wondered whether this deeper investment of time and effort by a few engineers to learn about IT was the best use of their time and talents. The core issue was not whether engineers should become more familiar IT systems in order to support the alignment, integration and functionality of IT and OT systems in support of the project; all respondents agreed on the need for familiarity. The concerns were mainly over how much overlap was needed between individuals and groups.

One engineering manager emphasized that, while hardware installation is typically a "pure" engineering problem, the information and data management technology side of grid modernization is very different from pure engineering, and there is a need to understand the differences to ensure that grid modernizations function as needed. This manager also posed a broader question about IT/engineering knowledge and roles that was raised by several respondents about depth: how much do engineers need to

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[22] Supervisory Control And Data Acquisition (SCADA) is used in multiple areas of most electric utilities and across all industries. In general, SCADA systems provide utilities with information and control capabilities to manage the grid. Modern SCADA systems have added new functionalities and features that support interactive, self-healing systems and devices that are characteristic of smart grids.

know about the IT systems, including database structures, data management, software programming and applications that support many smart grid technologies? Similarly, how much do IT professionals need to understand about engineering principles, systems and processes? One engineering manager described the initial differences in opinion among his engineering colleagues about the level of knowledge and role crossover that is needed. He noted:

> "It's about getting the right people, with the right skill sets, to do the right stuff. Some people will differ on this, but I recall from one group meeting a comment was, 'well, we need to know more about how databases work,' but why? You don't have to understand the code of Microsoft Excel to become a super user of it, to have it contain the data you need to do analytics, to optimize whatever business process you're the owner of. The paradigm shift is for people to understand and recognize that the engineering and operations function of which they're an owner, is complex enough as it is, that they don't want to be doing everything else too."

One engineering manager stressed that the more important goal should be developing a broader understanding about the impact of these technologies on overall business processes that affect the work of the organization. From his perspective, this should also be a greater focus in technical training programs:

> "People often raise the question whether engineering curriculum needs more IT-type training, so engineers can function at the OS-patching level and OS troubleshooting level, use tools to analyze process utilization, memory utilization, doing backups, etc. But that only makes sense if you make the delineation. Otherwise you'd argue you need to let the engineers do the specialty work of being metering systems experts, doing the analytics, but let IT-related work reside with the group that already has the skills to do that, using the people and skills we have in place today. So the training issue becomes less about technical training for operational engineers, and more about the need to do business impact training for technical employees in general."

Safety and Trust

Expanding employees' familiarity with systems changes and grid upgrades also has implications for the safety of front-line workers who are responsible for installing, repairing and maintaining the new systems. Although there are detailed procedures in place to ensure the safety of equipment installers and repairers, the use of advanced communications technology has enabled greater remote control of grid operations, which has also included enhanced systems and procedures for ensuring worker safety.

Even with the safety enhancements that technology offers, there can be a perception that greater reliance on automation or technology that is controlled from afar could compromise safety, especially for front-line craft workers. One operations manager described how he has had his line crews meet and spend time with power system operators (dispatchers) so they understood the relationship between their work and dispatch, but also so that they established personal relationships with dispatchers, who operate increasingly complex technologies to restrict or enable the flow of power across of the grid, including those sections where repairs are taking place. He explained:

> "What we've done in the past 4-5 years is, we have taken the control – which is really about life and limb – away from the hands of the lineman, and put it in the hands of somebody siting on the

fourth floor of our main building, to manipulate from a remote location. So, why do I want to put them in dispatch? It's to understand how the system works, to see the big picture, but it's also to develop relationships. So my lineman group that work here, we're on the same campus as the dispatchers that they talk to multiple times a day, but they are never face to face with them. A lot of the linemen have never met the dispatch group. It's a slight exaggeration, but they do put their lives in their hands every day so it's a lot easier to be able to do that with somebody you have a personal relationship with. It's absolutely a trust issue."

General Knowledge and Skills

The previous section revealed some of the context and situational challenges shared by smart grid demonstration projects as they worked to design and implement various project elements. The context for each project was consistently raised by respondents, who often described in great detail how context and implementation factors affected overall project success.

Respondents' perspectives on project design and implementation also revealed certain types of general, foundational knowledge and skills that were emphasized by many individuals and that cut across the different projects and occupations. These knowledge and skill areas are linked to many of the dominant themes expressed by respondents, but are not comprehensive. They provide a supplement to existing inventories of required knowledge, skills or abilities required by employees or identified as important for development.[23]

Systems Thinking

Respondents frequently emphasized that, while much of the technical work of designing, installing and maintaining the systems required for their projects has not changed appreciably, the work is more complex compared to past upgrade projects because it has required the integration of different types and layers of technology that is more advanced and that must function together to achieve the desired results. Many respondents reported there was a heightened need for employees who can envision how their work affects – and is affected by – the larger system within which they must operate.

Systems thinking was often described in theoretical terms or to describe engineering design or management functions where technologies, processes or behaviors influence one another. But the concept was also described as important to front-line workers who are responsible for installing, monitoring and maintaining the equipment. One operations manager noted:

> "For linemen, just because they can turn a wrench, doesn't mean they will be able to operate our electrical system in the future. As far as the actual application of an operation of physically installing the equipment, it's still fundamentally the same operation, requires the same tooling, but what we learned throughout the course of the project is that because of the technology involved in these, our linemen could not be complacent. They had to really put on their thinking caps and think about what was going on internally inside these devices and how the metering packages were going to work, what the coordination between the devices was going to be, how the integration of the physical componentry as well as the technology was going to work from a remote location. So I don't want to say there wasn't a huge learning curve because it's still fundamentally basic line work, installing the devices, but it did absolutely open the eyes of the linemen that this is a new day and age."

[23] Existing skill standards for many energy occupations currently exist and can be found at: www.cleanenergyexcellence.org or http://www.energy.wsu.edu/ResearchEvaluation/WorkforceDevelopment.aspx

The same manager tied the need for employees to engage in systems thinking in his description of the organization's plans to install an advanced Fault Detection Isolation and Restoration (FDIR)[24] application as part of their power distribution automation upgrade:

> "One thing is learning how the entire system operates synergistically. So with FDIR in the very near future the entire system from the morning to the afternoon could look completely different. It's that dynamic. So they (line workers) need to understand it both from an operational perspective as well as a philosophical perspective, an operating and switching perspective, how that going to be manipulated, and what that impact is on the work group."

Interdisciplinary Approach

A second aspect of systems thinking expressed by respondents was the benefit of including employees who have an interdisciplinary background in the projects, with knowledge of a broad range of subject matter, the ability to relate to a variety of topics and situations, and the ability to bring in information and perspectives from other fields of study. Knowledge of information technology, communications, computer programming, finance, business management and consumer behavior, for instance, were viewed as beneficial to overall project performance. Whether through their formal education and training or though experience gained on the job, respondents reported that while specialists with deep knowledge are critically important, breadth of experience and cross-occupation knowledge is valuable to project success because of the broad range of technologies, functions and expertise required.

This emphasis on interdisciplinary knowledge and preparation was noted as important for employees at multiple levels, whether for craft workers, engineers or managers. One demand-side (customer services) manager associated the general education required of students in four-year degree programs as an important source of this preparation in her area as well:

> "At the university level a lot of times there's core required classes that aren't necessarily anything to do with the student's major. They might be a philosophy or religion class. So, those kind of classes are good to be required. They help you think outside the box. They take you outside of your comfort zone. For some students that may be where they feel the most comfortable. I think academia does pretty well trying to provide students with that well rounded background."

The value attached to interdisciplinary knowledge pertained to employees at all levels; however, engineering was one area where the need for additional breadth of subject matter knowledge was stressed as especially important in a smart grid environment. Yet, as one engineer noted, it takes time and experience to develop a broad knowledge base: "You can't expect an engineering student to come out and know how to do all that's needed for smart grid implementation – you need experienced staff. Some have the technical foundations, and they've developed other skills – data management/analysis, IT, communications, systems integration, the business side – but that takes talent and time."

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[24] Fault Detection Isolation and Restoration (FDIR) is a process for monitoring a system, identifying when a fault (failure) has occurred, and pinpointing the type of fault and its location so it can be remedied. Its use is intended reduce the duration and extent of forced outages due to faults on the electrical distribution grid.

As one senior project engineer noted, while it may be unrealistic to put a new college grad in a leading role on an upgrade project, it does present an excellent training opportunity for a new engineer, and offers another way to help experienced engineers transfer their knowledge – from mentor to learner – and for both parties to see all sides of a project. A primary concern of this senior engineer was the industry and technical knowledge that will be lost due to the predicted retirement of many experienced power engineers in this decade.[25]

Transferring industry knowledge and experience to younger engineers was noted as important, but that process takes time and resources. Concerns about retirement were echoed by one industry expert, who believes that the departure of experienced engineers and craft workers could hamper efforts to implement smart grid upgrades. He indicated that he has already seen several experienced lead engineers from three different regional smart grid demonstration projects leave for retirement, and he believes many more will depart over the next few years. In his experience, the current success of regional smart grid projects have depended heavily on having technically competent employees who are also able to design, lead and manage the projects. Technical knowledge and experience convey the expert authority needed to command respect from colleagues and enables them to build the teamwork needed to achieve project success.

Engineering and Smart Grid Skills

Some respondents noted that their experience with the smart grid project caused them to question whether current college engineering programs are comprehensive enough to help students achieve the kinds of breadth in functional knowledge and subjects that have proven important to engineers who are now managing grid upgrades. One set of comments pertained specifically to the need for greater technical breadth for power engineering programs, including the need for greater programming skills and knowledge of information databases. Although many respondents agreed that undergraduate power engineering programs are already technically rigorous, some suggested that curriculum should be reviewed to be more responsive to changes in industry. Some typical topics and comments are provided below.

Programming Skills

One engineering manager noted: “From an engineering perspective I’d say it (a smart grid work environment) is going to be quite different from the stereotypical power education course that you would normally focus on for the utility industry. It will have to be more programing, and have more of that included than is what is normal for people going into power. A little more analog, high voltages, all that stuff. We’re finding with the DMS (distribution management system) that a lot of the skills needed are programing skills. Still needing both sides—the knowledge of how this transmission system works, how this substation works, to be familiar with it—but also have that programing kind of mind frame, those kinds of skills. We are lucky to have some people like that here, but I think that’s unique to have power engineers who also have that.”

[25] See: Hardcastle, A., Jull, P. & Zeiger Hanson, S. (2013). *Workforce Challenges of Electric Power Employers in the Pacific Northwest*. Washington State University Energy Program, for the Pacific Northwest Center of Excellence in Clean Energy. See: http://cleanenergyexcellence.org/resources/

Awareness of Customer Databases

One engineer suggested that engineering programs should include a survey-level course with general information about customer databases, how they are configured, and how to communicate with data managers. Another engineering manager added: "Having an understanding of customer database systems is important. It is important to know how and what to ask for when working with IT. Sometimes just one variable in the request can make the difference between a couple day turn-around and a couple week turn-around. This may not require formal training but it is important, so it should be part of an intentional OJT (on-the-job training) effort."

Distribution Automation

In considering the preparation of new power engineers hired at his company, one senior project engineer reported that some programs have not kept up with rapid advancements in distribution automation. "I'm not sure if EE Power engineering curriculum and students actually have enough breadth in curriculum at the undergrad level. Automation on distribution grid – there's a lack of foundation in that area. There doesn't seem to be much training in that at the undergrad level. I teach parts of an automation class, and I see that with a lot of the other power curriculum it doesn't change that fast, it stays the same, but with the smart grid area, it's just changing so rapidly it's really hard to keep up with the new advances." One senior technology expert added his observation that the emphasis on distribution automation is important because of the complexity of the distribution function. "Transmission is relatively simple compared to distribution, where there are many new technologies, lots of integration issues. It's far more complex (than transmission)."

Non-Technical Knowledge and Skills for Engineers

Another set of comments regarding engineering preparation focused on non-technical knowledge and skills that are often learned on the job rather than through formal education or training programs. Some respondents speculated that much of this training is not offered as part of established power engineering programs, and that individual organizations prefer to provide related training internally. Whatever the case, many respondents stressed that these topical areas have proven to be very important to successful project implementation.

Group Projects/Interdisciplinary Exposure

One engineering manager described how the structure of her undergraduate electrical engineering experience included very limited exposure to group work and interacting with individuals with different academic backgrounds – experiences that she regarded as increasingly valuable in the workplace. "The only group project was my senior design project. Most of the other coursework was working as an individual. Graduate programs require group projects, but you need more group projects in undergrad programs. That's beginning to change, but we need more of that. It would really model more of what they'll see in the workforce. Also, projects that connect different kinds of people, with different skills sets, more interdisciplinary work. We need to model what's happening in the workplace."

Understanding Customer Behavior

Several engineers emphasized the need to understand how customers' acceptance of technology changes, including participating in implementation. "There's a need to include customer behavior and psychology in power engineering training. The success of smart grid hinges on customers' awareness and willingness to support and use the new capabilities available. It's a social and technical challenge, and it's an area few engineers are trained in—and it is beyond what most academic programs teach." Another project engineer added: "Power engineering programs could and should include a consumer behavior psychology aspect to the program. It is important to understand from the beginning that this is part of the smart grid equation. It is hard to imagine a utility offering training on this topic. It should happen in the engineering programs."

Project Management and Coordination

Managers and project staff across several different functional areas and departments – from engineering to operations and customer support – commented on the importance of solid project management skills to enable smart grid implementation projects to run smoothly. It was an area generally identified as important for the successful implementation of any type of project, but also as a skill that is not typically found among new hires, especially new college graduates. Although these employers do not expect inexperienced employees to take the lead for high-stakes projects, most respondents emphasized the need for project management training within apprenticeship or degree programs so that younger employees have a foundation to develop through experience, ideally through their involvement in group projects and activities that enable them to learn and practice proven project management techniques.

The models employed to manage smart grid projects varied, yet most approaches were reported to be generally effective for supporting the objectives of the project. Project delays or discrepancies were usually attributed to unforeseen technical problems or the compressed time schedule, not to the project management plan or structure per se. For one organization, the lead project manager acted as the primary "air traffic controller" for the project, tracking project obligations and deliverables, monitoring vendor relationships, and coordinating project stakeholders in support of the project. In this case, the project management model evolved to fit the project as it developed, largely in an *ad hoc* fashion, with good success.

The importance of having one point of contact for questions and communications about the project was stressed by respondents. In a large organization with multiple, concurrent upgrade projects underway, the general model used was much more structured and linear, which was reported as effective and appropriate for the large scope of work involved. One demand-response services manager noted:

> We make it very clear who is in charge and in control. You've got a project manager (PM) that you roll up to. So even though they might be your peer they're still in charge of this particular component to make it happen. Then we all roll up to the main PM. We do approach this from a very much team concept, but somebody has to be in charge of 'where are you at on this, because so-and-so is expecting that piece to be finished before they can do what they need.' This is how it all works together. It's not really taught in school. It is pretty vital to getting the stuff off the ground.

In several instances, project managers were praised for their effective people management skills, which several respondents noted were key to establishing teamwork and motivating project partners to perform at a high level, often under tight timelines. Those who went out of their way to support team members;

remove roadblocks to project implementation; and encourage respectful, results-oriented dialogue between staff and departments were especially appreciated. One respondent noted that technical expertise has been a necessary but not sufficient condition for effective project leadership and management; "They also need to have the ability to lead and manage people, which is often the harder aspect than the technical. You need both."

"Big Data" Analysis and Management

Many respondents noted the importance of enhancing the data and analysis skills of employees at many levels, even though the topic of data collection, analysis and management was most often described in terms of the relationship among information technology, engineering and operations management.

As noted earlier, the projects reviewed for this study were just beginning to collect and analyze customer data. One project manager noted: "Our ability to organize, analyze, understand and apply data is a challenge. There are now many more data points under smart grid – it's a wave of information. But how best to use it, mine it, apply it? For customers, too. Many of our employees are affected, but for most of these projects the big data work is just beginning."

As one smart grid expert noted, while smart grid systems and processes rely heavily on collecting data, the value is in interpreting its meaning. He noted that the analysis and management of big data is not a core strength of most utility organizations, and many questions remain about how this function should be supported. Many organizations are unsure how to proceed:

> Data is pretty useless if you can't make sense of it. Utilities are now hiring high-level consultants to do 'big data' analysis for them. Will they need to develop internal talent? You'll have to convince utilities that they're going to have to re-think how they analyze all this information. But it will probably continue to evolve, it's not something we do for a while then that's it. So the question is, will they try to keep up, make investments for the long-term?

As some respondents noted, the idea of managing and making sense of large amounts of data often seems overwhelming, in part because it represents new territory for utilities, even for those who have acquired or prepared staff and have a plan in place for that stage of their project. One respondent noted that what appears on its surface to be a specialized, high-level analytical function reverberates throughout all levels and employees in the organization:

> This idea of more data coming in, reams of it, and having to have people who can set up protocols and systems to extract or curate data, figure out what's relevant, and figure out ways to deploy and use it for decision making. That is all the way down to the field technician who is looking at readouts, where they used to be looking at mechanical devices, and trying to make sense of what that means for their job in the field.

Educating and Serving Customers

An important component of smart grid upgrades is engaging customers and encouraging them to use energy more efficiently based on price signals, incentives and other benefits, so the topic of data management, analysis and support naturally extends to the systems and staff that support demand-response outreach, information systems and customer service. Here too, the expectation that energy consumers will interact with their own energy data to make decisions about services and efficiency generates new expectations about the level of customer services available to consumers, and the knowledge and skills expected of employees.

Several customer service representatives (CSRs) noted that where the demonstration projects are rolling out to consumers, they have spent much more time than in the past explaining basic energy terminology and technology to consumers, such as defining “peak time” and what a kilowatt is. CSRs spend much more time explaining the incentives and benefits to consumers, guiding them through websites, and helping them navigate and understand their own energy data.

Several respondents noted that, for many older customers (and some CSRs), computer and IT systems pose some challenges, which require a higher level of personal support, often akin to being a technology help-desk for customers. While younger employees are often more familiar with IT and related software applications, which is an advantage, experienced employees bring deep knowledge of the organization and the energy industry that is needed to solve complex customer questions and problems. In most cases, complicated questions and related technical problems are referred to project coordinators or managers who understand the technology changes or can interface with technical staff for answers.

Most of the training for CSRs has been provided internally by engineers, managers and project specialists. This training has included energy and smart grid basics, updates on new computer applications, websites and preparing for customer questions, and developing internal resources available to CSRs. Most respondents said they felt prepared to support customers and meet their needs as the project rolls out to targeted consumers and expands across their service area.

Training for Success

OJT was the most common strategy employed by demonstration projects to prepare and upgrade the knowledge and skills of project staff and stakeholders for project success. As one project lead noted: “A lot of our training has been internal, OJT, figuring it out as we go, interaction between employees. That’s 80-90% of how we went about training of engineers, other employees for the demonstration projects.”

Project leaders typically leveraged the skills of existing employees and product vendors, scheduled one-on-one mentoring sessions to encourage knowledge-sharing, and supplemented those strategies for other project members through internally developed orientation training or even targeted professional development through industry or technology-focused conferences. Some individuals and departments even reached out to other utilities and individuals who had already implemented some system components or plans regarding equipment, integration, and implementation to benefit from those lessons learned. Many respondents asserted that continued education and upgrade training in both technical and non-technical topics will be needed by employees to ensure that they are equipped to support future grid modernization.

Key Knowledge and Skill Areas

The following table provides a short summary of the topics, knowledge and skill areas that emerged as especially important to the current and future success of the smart grid demonstration projects. Some topics represent subject matter and competencies that might typically be expected of individuals in these occupational groups, whether or not grid modernization is underway, but which were emphasized by respondents. Thus, the table is not a comprehensive list of the core work functions, activities or competencies expected of the occupational groups or for specific jobs.[26]

Occupational group(s)	Key knowledge/skill areas identified by respondents
Engineering	• Information systems/information technology; customer database structure, organization; system/data security • Distribution automation • Computer science: programming/application development • Interdisciplinary knowledge: business process fundamentals, management, economics, science, consumer behavior and psychology, communications • Project management • Group/team-based project design and implementation
Operations (Line and Meter Technicians)	• Systems thinking/knowledge • IT knowledge/computer use • Data analysis/interpretation/communication • Software application proficiency (Microsoft Office suite, related). • Upgraded technical/device knowledge and skills: programmable logic controllers, electronic components and circuits, digital electronics, etc. • Direct customer services: devices and connectivity, user data and controls, website use, appliance/equipment options and pricing, incentives
Customer Service/ Customer Support	• Energy and utility basics: principles, concepts and grid technologies • Customer data/database content and organization • Data manipulation, analysis and interpretation: company and user data • IT knowledge and software use, website organization, web tools and applications, troubleshooting • Operations technologies: remote switching, metering, applications • Energy advising and customer consulting

[26] For more detailed information and research regarding position descriptions, competencies, education and training programs and curriculum for many of these occupational groups described in this has been the focus of the Smart Grid Workforce Training grant through the Pacific Northwest Center of Excellence for Clean Energy: www.cleanenergyexcellence.org.

Conclusions

The interview data collected for this report, although limited in scope, suggests that upgrading the electrical grid is only possible because of the availability of advanced technologies that will make the existing grid function more effectively and able to more efficiently integrate new sources of energy generation, transmission and distribution, while providing higher levels of service to customers. At the same time, input from industry observers and employees who are now implementing grid upgrades lend support to the theory that smart grid upgrades are more than just the implementation of technical changes. Rather, these technical changes are introduced into and interact with a complex socio-technical system that affects the experiences, behaviors and knowledge requirements of individuals and groups who work with smart grid technologies.

Respondents' comments provided insights on many different dimensions of their demonstration projects, all of which have some bearing on the knowledge, skills and abilities that are associated with smart grid upgrades. These environmental, contextual and knowledge-foundational dimensions are not discrete elements, nor are they comprehensive. However, they were emphasized by the majority of respondents as important factors in the design and implementation of their grid upgrade projects. Respondents generally cited the successes and accomplishments of their projects, and it is important to note that those comments far outweighed mention of the difficult challenges they faced in designing and implementing grid modernization. It was the description of challenges, however, that highlighted some of the more valuable insights reported by respondents, which is why they are emphasized throughout the report.

The most notable of these challenges are described below.

Environmental Factors

This refers to the broader external conditions and factors identified by respondents that affected the structure and support for project work. These conditions also influenced important decisions about project design, implementation and management.

Federal Funding Awards

The award of federal funding to extend current work and initiate new smart grid project work was a mixed blessing. While the award allowed project partners to accelerate modernization work and test new approaches, the award also created new expectations and aggressive timelines for project work that was highly visible to management. "Drinking from a fire hose" was how one project manager described the experience.

Revolution vs. Evolution

The projects typically extended or leveraged work that most utility partners were already engaged in, thus adding new technical components, vendors and partners represented a natural evolution of work that was planned or otherwise seen as necessary. But some respondents noted that the complexity of the project elements, new technologies, staffing, and the pace of project schedules and components sometimes seemed overwhelming and generated some internal resistance from the conservative culture of utility organizations and some employees.

Contextual Factors

This dimension refers primarily to some of the technical, social and business process elements that are relied upon to design, implement and support smart grid projects. They include internal staffs and departments as well as critical external partners such as vendors and consultants.

Coordination: Technical and Social

The importance of continuous coordination and team building among design and implementation partners was emphasized as critical for project success. Effective internal and external coordination among individuals and departments across the organization, including with external partners such as vendors, was stressed as important. The risks associated with weak coordination and participation on schedules, workload and performance can be high.

Vendors and Technologies

All projects relied heavily on outside vendors and consultants for grid products and support for installation and integration. Schedule requirements and a lack of internal knowledge and expertise about new products – along with limited vendor/consultant knowledge of systems integration – generated delays and added workload for existing project staff.

Interdependence: Information Technology and Operations

Smart grid requires a high level of integration among IT, operations and communications technologies. Collaboration among departments is essential to ensure effective integration, but this also requires employees to increase their knowledge about each of these technologies and processes. Having a broader understanding also means knowing how these systems affect business processes across the entire organization.

Roles and Expectations

While some crossover in systems knowledge and skill is beneficial, at the same time it can be difficult to define how much employee knowledge-sharing and cross-training are beneficial for the project. Each of these major systems is complex and it is not practical or effective for employees to be expected to have deep knowledge in multiple areas. Understanding the impact of these integrated systems on the overall business is also important.

Safety and Trust

Smart grid technologies have generally enhanced the safety features in place to ensure the safety of operations and maintenance personnel, but greater reliance on automation and remote control of grid operations sometimes increases the perceived risks to front-line employees. Orientation and limited cross-training between dispatchers and operations personnel increases understanding, encourages teamwork, reaffirms safety procedures, and helps to build trust.

Knowledge-Foundational Factors

This dimension refers primarily to conceptual and applied content areas, practices, knowledge and skills identified by respondents as important to developing and conducting smart grid projects.

Systems Thinking

Smart grid systems and technologies are complex and operate interdependently. Employees at all levels need to understand how these technologies work together and how the work they do and the actions they take affect – and are affected by – the different parts of the system, including functional areas, departments, and employees in their own groups and others.

Interdisciplinary Approach

Employees who have a broad knowledge of different subject matter and the ability to relate that knowledge and experience to their work have great utility in a smart grid environment. Specialists with deep subject knowledge continue to be important, but the ability to draw from many disciplines and experiences enables employees to grasp the complexities of the many facets of grid modernization and to contribute in unique ways. Some technical training and university power engineering programs and research centers have already become more interdisciplinary in their design and offerings, integrating instruction in economics, business, public policy, law and social sciences.[27]

Engineering and Smart Grid Skills

Several respondents suggested that existing power engineering programs should be reviewed and upgraded to include or expand their emphasis in several technical and non-technical areas. Many of these areas also pertain to the operations, managerial and customer service occupations described in the study.

Technical

- **Computer and software programming**: These disciplines are especially to support distribution management systems and technologies, system and data security.
- **Big data analysis and management**: Technology has enabled two-way flows of information that are data-intensive and complex. Engineers and employees at all levels must be able to analyze, interpret and manage larger amounts of data to support smart grid systems and customers.
- **Customer databases**: A general overview and understanding of database structures and content of customer information systems.
- **Distribution automation**: Increasing the emphasis and breadth for undergraduates to keep pace with rapid changes in this technology.

Non-technical

- **Project management and coordination**: Project management skills are critically important but not often taught in college engineering or craft-oriented technical programs. Project management includes "people" management, which is also critical to ensure project success.
- **Educating and serving customers**: Encouraging and supporting customers to use energy efficiently is a central feature of smart grid modernization. Demand-response coordinators and customer service specialists must have the ability to educate customers, and serve as advisors and consultants who

[27] In Washington, for instance, power engineering programs available at Washington State University, the University of Washington, Western Washington University and others include broad interdisciplinary content and research opportunities for students.

understand customer data, can solve problems, and offer effective solutions, choices and even technical support to consumers.

Key Knowledge and Skill Areas

The knowledge and skill areas identified by respondents pertain primarily to engineering, technical operations, and customer service/support occupations. While the table of technical and non-technical topics provided above included topics that were identified by many respondents as particularly important to the smart grid upgrade projects they were engaged in, those topics do not represent a comprehensive list of knowledge or skill areas. However, the topics named do represent areas that should be used to guide the review, development or improvement of university, two-year college, apprenticeship, and other education and training programs so they are responsive to the needs of employers and the workforce in a smart grid environment.

Appendix A

Electrical Grid History and System Description

The U.S. electric grid stands as perhaps one of the great technological and engineering achievements of all time, and certainly can be held up as one of the great achievements of the last 100 years.

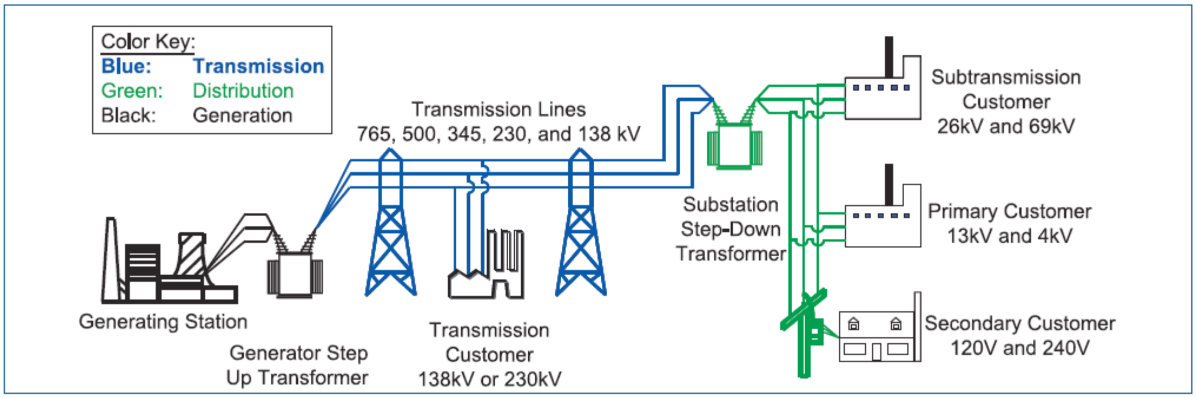
In the late 19th century, electricity was generated and consumed in low voltage, direct current (DC) systems. The nature of this generation and consumption model meant line losses over large distances were prohibitively large, and compelled planners to situate generators very near to their loads. In the late 1880's, however, early explorations into high voltage alternating current (AC) systems were being tested, and in 1888 Nicola Tesla would present what would prove to be a revolutionary vision for a fully integrated high voltage alternating current (HVAC) system for generating, transmitting, distributing and consuming electric power. The Westinghouse Company, which owned the patents for Tesla's transformers and motors, began the process of electrifying North America.

The basic system, initially designed by Tesla and deployed during the last years of the 19th century and the beginning of the 20th century, is still in use today. The heart of the electric grid are the thousands of generating stations, located at various points across the country, which together supply over 950,000 megawatts of generating capacity. These generators produce alternating current electricity which is synchronized at the point of production to the exact frequency of the entire grid, at between 10,000 and 25,000 volts. These generating plants include thermo-electric plants such as nuclear, coal, oil and natural gas, and also include non-thermal generating plants such as hydro-electric and solar photovoltaic facilities.

From the generators, the electricity is run through step-up transformers, which use intertwined sets of electric coils to "step up" the voltage of the electricity to between 138,000 volts (138 kV) and 765,000 volts (765 kV), which allows the electricity to be transmitted over great distances with minimal line losses.

After travelling across high-voltage transmission lines, sometimes for hundreds of miles, the electricity arrives at a substation, where it is processed through step-down transformers and converted into lower voltage levels appropriate for final distribution to customers. Most often, a final transformer will again reduce the voltage of electricity just before it is provided to the customer, and this voltage level can vary from 120 volts for residential customers to 115,000 volts for some large industrial facilities.

The figure below provides a basic illustration of the current electric grid (U.S. Canada PSOTF, 2004).



In the United States today, while we most often refer to “the” electric grid, in point of fact there is not one grid, but three. The Western Interconnection, Eastern Interconnection and the Energy Reliability Council of Texas all operate as separate and distinct electric grids. Within each of these grids, however, every generator, every transformer, every substation, every motor, every street light and computer, are all connected as one massive, synchronized, elegant and constantly operating machine.

Summary of Smart Grid Technologies

Summarized below are the five major categories of smart grid components identified by the National Energy Technology Laboratory (NETL, 2007b).

Advanced T&D Components

Advanced transmission and distribution components rely upon innovative power electronics and superconductive materials to manage the transmission and distribution of electricity. Gains in power electronics and superconducting materials will allow for efficient switching processes, voltage regulation and reactive power management. Advances in solid-state AC/DC converters might also make cost-effective the incorporation of high efficiency, low loss transmission capabilities, such as High Voltage Direct Current applications, which can transmit power with little losses over long distances (NETL, 2007c).

Advanced Controls

Advanced controls consist not only of the physical devices but also the intelligent software tools which will “analyze, diagnose, and predict conditions in the modern grid and determine and take appropriate corrective actions to eliminate, mitigate, and prevent outages and power quality disturbances” (NETL, 2007a). Together with sensing and measurement capabilities and a robust communications system, these controls will provide the grid with the capability to “self-heal” in the event of a disruptive event (Dodrill, 2010).

Sensing and Measurement

Traditional electro-mechanical equipment designed to measure system state attributes such as watts, watt-hours, VArs, phase angles, harmonics, etc. are beginning to transition to solid state digital electronics capable of interfacing with real-time communications systems (NETL, 2007a). Synchrophasor Measurement Units (also called Phasor Measurement Units of PMUs) use global positioning satellite technology to take measurements across wide areas and even between multiple organizations which are time-synchronized to provide a wide area overview of the state of the grid.

These advances will allow for transmission and distribution systems to see a "real time" picture of the grid's health and wellbeing in a faster and more complete manner than ever before. When combined with advanced analytic and controls systems, this provides a powerful suite of tools which can provide the grid with real-time sensing and response capabilities.

The sensing and measurement section also includes Advanced Metering Infrastructure (AMI) or so-called "Smart Meters." Indeed, smart meters are the device most commonly associated with the Smart Grid within the public's mind, as millions of smart meters continue to be installed nationally through both privately and publically funded projects.

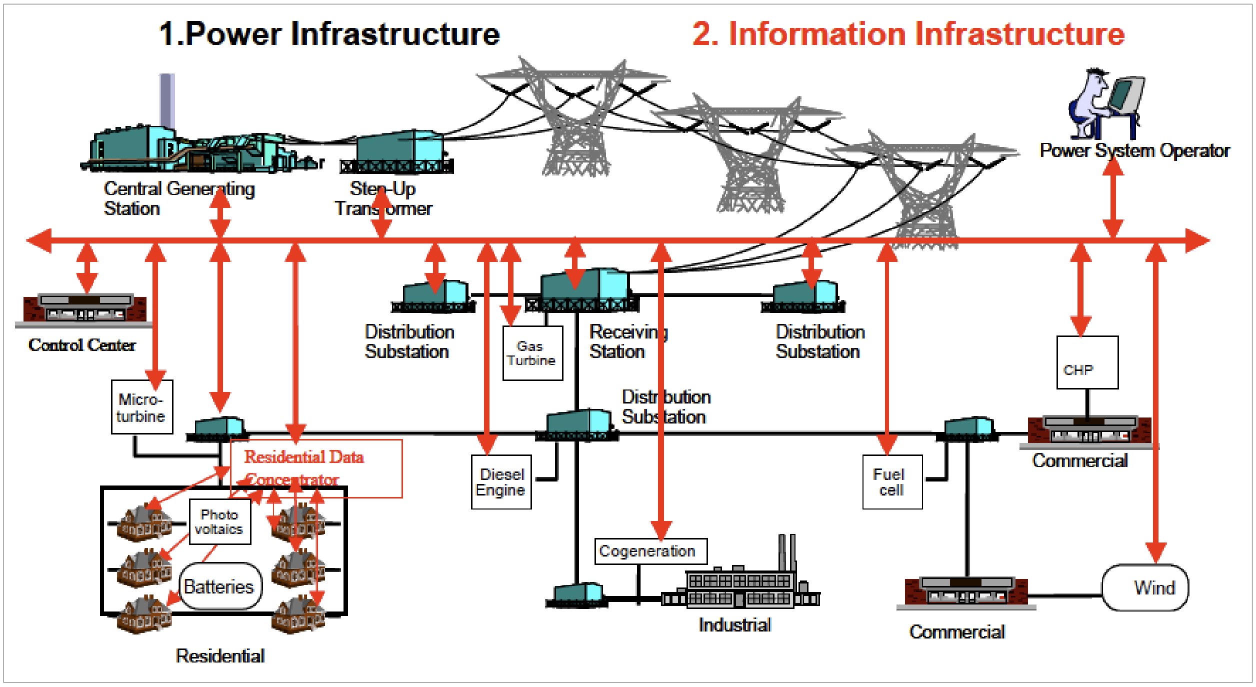
Improved Interfaces and Digital Support

The increased speed with which information can be gathered and transmitted using Smart Grid technologies allows for the development of advanced interfaces which improve the human system operator's ability to quickly analyze and respond to grid events. These technologies must allow for the vast amount of data collected by sensors operating throughout the generation, transmission, distribution and consumption elements of the grid to be transformed into useful information which can be leveraged in real time (NETL, 2007e). These systems will also automate many of the lower level processes of system management, allowing grid operators to focus on higher level system dynamics and intervene when necessary (NETL, 2007e).

Integrated Communications

All of the various smart grid technologies must be built upon a fast, reliable and secure communications network, which allows for "plug and play" integration of new technologies and tools as they are developed. This network must be able to span multiple communications methodologies, from cellular networks to radio mesh, to Broadband over Power Line (BPL) (NETL, 2007d).

The following figure illustrates a full power system with high speed integrated communications infrastructure, courtesy of the Electric Power Research Institute (Hughes & others, 2004).



1.Power Infrastructure
2. Information Infrastructure
Power System Operator
Central Generating Station
Step-Up Transformer
Control Center
Distribution Substation
Gas Turbine
Receiving Station
Distribution Substation
CHP
Micro-turbine
Distribution Substation
Residential Data Concentrator
Diesel Engine
Fuel cell
Commercial
Photo voltaics
Batteries
Cogeneration
Industrial
Commercial
Wind
Residential

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