PDHonline Course E305 (5 PDH)

Smart Grid

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The Smart Grid

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Introduction

Throughout the 20th century, the U.S. electric power industry has served our nation well, providing adequate, affordable energy to homes, businesses, and factories. This state-of-the-art system has brought a level of prosperity to the United States unmatched by any other nation in the world. But a 21st-century U.S. economy cannot be built on a 20th-century electric grid.

Many agree there is a need for major improvements in the nation's power delivery system and that advances in key technology areas can make these improvements possible.

This course is based on a DOE report which essentially describes a roadmap for the transformation of the current grid structure to meet future needs. The original document was written in 2009 and is somewhat dated, but the fundamentals presented in this document are still valid. Some concepts presented by the DOE have occurred and many are slowly beginning to take hold in the utility industry. Other concepts are years away. And there have been new concepts introduced since this report was issued, such as microgrids and the proliferation of shale oil which has fundamentally changed the generation markets and resulted in greatly reduced emissions resulting from the production of electricity.

The Modern Grid, as defined by the DOE, sets the foundation for a transition that will focus on meeting the six key goals discussed below:

1. The grid must be more reliable

- A reliable grid provides power dependably, when and where its users need it and of the quality they value. It provides ample warning of growing problems and withstands most disturbances without failing. It takes corrective action before most users are affected.

2. The Grid must be more secure

- A secure grid withstands physical and cyber attacks without suffering massive blackouts or exorbitant recovery costs. It is also less vulnerable to natural disasters and recovers more quickly.

3. The grid must be more economic

- An economic grid operates under the basic laws of supply and demand, resulting in fair prices and adequate supplies.

4. The grid must be more efficient

- An efficient grid takes advantage of investments that lead to cost control, reduced transmission and distribution electrical losses, more efficient power production and improved asset utilization. Methods to control the flow of power to reduce transmission congestion and allow access to low cost generating sources including renewables will be available.

5. The grid must be more environmentally friendly

- An environmentally friendly grid reduces environmental impacts through initiatives in generation, transmission, distribution, storage and consumption. Access to sources of renewable energy will be expanded.

6. The grid must be safer

- A safe grid does no harm to the public or to grid workers and is sensitive to users who depend on it as a medical necessity.

It is believed that achieving these goals will result in a "Smart Grid" that will exhibit the following seven characteristics.

1. Self-Healing

First, the grid will heal itself. The modernized grid will perform continuous self-assessments to detect, analyze, respond to, and as needed, restore grid components or network sections. It will handle problems too large or too fast moving for human intervention. Acting as the grid's "immune system", self-healing will help maintain grid reliability, security, affordability, power quality and efficiency.

2. Engage Consumers

Second, it will motivate consumers to be an active grid participant and will include them in grid operations. The active participation of consumers in electricity markets brings tangible benefits to both the grid and the environment, while reducing the cost of delivered electricity.

In the modernized grid, well-informed consumers will modify consumption based on the balancing of their demands and the electric system's capability to meet those demands. Demand for new cost-saving and energy-saving products will benefit both the consumer and the power system.

3. Resist to Attack

Third, the Modern Grid will resist attack. Security requires a system-wide solution that will reduce physical and cyber vulnerabilities and recovers rapidly from disruptions. Both its design and its operation will discourage attacks, minimize their consequences, and speed service restoration.

It will also withstand simultaneous attacks against several parts of the electric system and the possibility of multiple, coordinated attacks over a span of time. Modern grid security protocols 4impact on the grid and the economy. A less susceptible and more resilient grid will make it a less desirable target of terrorists.

4. Enhanced Power Quality

Fourth, the Modern Grid will provide the level of power quality desired by 21st century users. New power quality standards will balance load sensitivity with delivered power quality at a reasonable price. The modernized grid will supply varying grades of power quality at different pricing levels.

5. Readily Accommodate All Generation Options

Fifth, the Modern Grid will accommodate all generation and storage options. It will seamlessly integrate many types of electrical generation and storage systems with a simplified interconnection process analogous to "plug-and-play" technology of the retail computer industry.

Improved interconnection standards will enable a wide variety of generation and storage options. Various capacities from small to large will be interconnected at essentially all voltage levels and will include distributed energy resources such as photovoltaic, wind, advanced batteries, plug-in hybrid vehicles and fuel cells. It will be easier and more profitable for commercial users to install their own generation and electric storage facilities.

6. Enable Competitive Markets

Sixth, the Modern Grid will enable markets to flourish. Open-access markets expose and shed inefficiencies. The Modern Grid will enable more market participation through increased transmission paths, aggregated demand response initiatives and the placement of energy resources including storage within a more reliable distribution system that is closer to the consumer.

7. Optimize Asset Use

Finally, the Modern Grid will optimize its assets and operate more efficiently. Asset management and operation of the grid will be fine-tuned to deliver the desired functionality at a minimum cost. This does not imply that assets will be driven to their limits continuously but rather that they will be managed to efficiently deliver what is needed when it is needed.

Improved load factors and lower system losses are cornerstone aspects of optimizing assets. Additionally, advanced information technologies will provide a vast amount of data and information that will be integrated with existing enterprise-wide systems, significantly enhancing their ability to optimize operations and maintenance processes.

These seven characteristics describe a grid that is generally more resilient and distributed, more intelligent, more controllable, and better protected than today's grid.

Advancements in large, centralized generating stations and higher capacity, more controllable transmission lines will continue to be needed and will complement the benefits of shifting to a more distributed grid model. This vision will enable the Modern Grid to benefit from better utilization of the transmission and distribution systems and active involvement by end users to meet the 21st century needs of consumers and society. Significant opportunities exist to apply modern communications, computing technologies and advancements in materials to achieve this Modern Grid vision.

Chapter 1
Self-Healing Grid

The first characteristic of a smart grid is known as self-healing. The premise of a seal-healing grid is stated as follows,

A self-healing grid is an engineering design that enables the problem elements of a system to be isolated and, ideally, restored to normal operation with little or no human intervention. These self-healing actions will result in minimal or no interruption of service to consumers.

The modern, self-healing grid will perform continuous, online self-assessments to predict potential problems, detect existing or emerging problems, and initiate immediate corrective responses. The self-healing concept is a natural extension of power system protective relaying, which forms the core of this technology.

A self-healing grid will frequently utilize a networked design linking multiple energy sources. Advanced sensors on networked equipment will identify a malfunction and communicate to nearby devices when a fault or other problem occurs. Sensors will also detect patterns that are precursors to faults, providing the ability to mitigate conditions before the event occurs.

The self-healing objective is to limit event impact to the smallest area possible. This approach can also mitigate power quality issues; sensors can identify problematic conditions and corrective steps can be taken, such as instantly transferring a customer to a “clean” power quality or source.

Another element of self-healing is the avoidance of high-risk situations. When impending weather extremes, solar magnetic disturbances, and real-time contingency analyses are incorporated into a probabilistic model, grid operators will be better able to understand the risks of each decision they may make, as well as ways to minimize those risks. In such applications, the expected volume of real-time data is high. And it will be necessary to integrate those data up to the control area, regional transmission organization level, NERC Region level, or the entire national grid, including its interconnections with Canada and Mexico.

While advanced sensing, analysis, protection, and control are important elements of a self-healing grid, so too is a robust T&D infrastructure. High-capacity circuit ties joining major Regional Transmission Organizations (RTOs) allow for inter-region power flows in an emergency. But if this power transfer capability is not adequate, then upgrades to higher capacity or the construction of new tie lines is required. This infrastructure improvement would also result in more robust energy markets, allowing less expensive generating unit power to flow to areas of high-cost congestion.

Current State

Today's transmission grid was designed with many self-healing features. Auto-reclosing and auto-sectionalizing are common techniques employed to maintain loads under adverse conditions. The network mesh design of the transmission system is self-healing due its built-in redundancy and such protective relaying features as high-speed reclosing and single-phase tripping.

System planners have historically modeled the transmission system to verify that, under a normal system configuration, assumed loads could be met even during expected peak conditions. In addition, planners ensured that these same loads could be met even with the failure of single (known as "N-1" contingencies), and in some cases, multiple lines, or components.

Sophisticated protective relaying schemes are in place to monitor system conditions and take corrective action should specific parameters exceed their limits. Transmission lines and equipment are tripped when conditions require, and most loads normally are not impacted by a single fault because the system can tolerate a single contingency. Substation automation and new intelligent electronic devices have taken transmission protection to the next level.

The design of the current transmission system incorporated the notion of self-healing many years ago and utilized the technologies, processes, and techniques available at the time. Significant advances in digital technologies, correctly applied, will dramatically improve this self-healing capability.

At the distribution level, new distribution automation (DA) technologies are being deployed to increase reliability and efficiency. DA applications improve the efficiency of system operation, reconfigure the system after disturbances, improve reliability and power quality, and identify and resolve system problems. Many DA applications can also be extended to coordinate with customer services, such as demand-response, and distributed energy resources (DER). In addition, distribution systems that include feeder-to-feeder backup allow enhanced DA functionality. These new approaches are directionally consistent with the vision of the self-healing feature of the modern grid. DA is integral to the concept of a self-healing grid.

Distribution Automation (DA) is a process that reconfigures the network, adds capacitor, and adjusts voltage as necessary to maintain the desired level of reliability.

Distributed Energy Resources (DER) are small alternative energy sources such as photovoltaic systems, solar thermal, CHP, and wind systems.

The current distribution system, without distributed resources and without an intelligent networked configuration, has been handicapped from a self-healing perspective. Today most DA and substation automation systems are applied at a local level, using local information for decision-making. The basic design of the integrated transmission grid - many geographically diverse generation sources feeding a high-voltage networked transmission system - is conducive to self-healing. On the other hand, the fundamental design of today's distribution systems cannot, in most cases, incorporate the depth of self-healing found on today's transmission systems.

Future State

The self-healing feature of the modern grid, at both the transmission and distribution levels, will advance from its current state by integrating advanced capabilities in the following areas:

Look Ahead Features
Analytical computer programs, using accurate and near real-time state estimation results, will identify challenges to the system, both actual and predicted, and take immediate automatic action to prevent or mitigate the event. Where appropriate, and when time allows, these algorithms will also provide options for the system operator to manually address the challenge.

Probabilistic risk analysis, also in near real time, will identify risks to the system under projected normal operating conditions, single failures, double failures, and out-of-service maintenance periods.

Load forecasting will be greatly improved to support more accurate look-ahead simulations. These simulations will be performed over various time horizons - minutes, hours, and days in support of operations; monthly, quarterly, and annually to support O&M planning activities; and longer range to support investment decisions.

Monitoring Features
Real-time data acquisition, employing advances in communication technology and new, lower-cost smart sensors, will provide a significantly larger volume and new categories of data, such as wide-area phasor measurement information. This dramatic increase in the volume of real-time data combined with advanced visualization techniques), will enable system operators to have an accurate understanding of the power delivery system's health.

By analyzing equipment condition data - including high frequency emission signatures - condition monitoring technologies will provide additional perspectives on the consequences of potential equipment failures. State estimators will take advantage of advanced data acquisition technologies and powerful computers that enable them to solve problems in seconds or less.

Advanced visualization techniques will consolidate data and present the appropriate information to operators in easily understood formats. Command and control centers at the regional level for transmission operations and at more local levels for distribution operations will serve as hubs for the new self-healing features.

Protection and Control Features

Advanced relaying will be employed to communicate with central systems and adapt to real-time conditions. High-speed switching, throttling, modulating, and fault-limiting devices will dynamically reconfigure the grid, including faster isolation and sectionalization as well as rapid control of real and reactive power flows in response to system challenges. Intelligent control devices, such as grid friendly appliances, will modulate load requirements in response to dynamic grid changes

Distributed Technology Features

Distributed generation and energy storage technologies will be widely deployed, particularly at the distribution level, and dispatched as system resources in response to self-healing needs. DER will also be used to support local circuit needs.

Transformation of the distribution system from a radial design to an intelligent network design, through the addition of circuit-to-circuit ties, the integration of DER and DR and the application of advanced communication technology will create a self-healing infrastructure.

DR programs will be widely expanded and utilized as system resources to assist in the management of system overloads, voltage issues, and stability issues. DR will also be used to support local circuit needs. DA will be further expanded and integrated with widespread DER/DR and, in conjunction with new operating and visualization tools will enable successful dynamic islanding.

Critical system components will be "hardened" where appropriate, including redundant designs and in-place spares. These advances will together create a sophisticated self-healing capability in the modern grid that will dramatically improve its overall reliability, efficiency, safety and will also increase its tolerance to a security attack.

The predictive nature of the modern grid, coupled with its ability to implement corrective actions in real time, will provide a major improvement in reliability at the transmission, distribution, and consumer level. Advancements in high-speed analytical tools that can determine system state, identify system challenges both deterministically and probabilistically, and determine options for preventing or mitigating negative consequences will be keys to improving reliability.

High-speed switching and "throttling" devices can correct system parameters prior to the occurrence of negative consequences. The self-healing feature of the modern grid will go beyond the prevention and mitigation of outages and will include monitoring of system equipment and consumer portals to identify both emerging and actual power quality issues. If a low or unbalanced voltage condition occurs on a distribution network, that condition will be monitored, and an appropriate corrective action will be taken. If harmonics or other sustained or intermittent power quality issues are detected, these conditions will likewise be corrected.

Generators, transmission owners and operators, and distribution companies will benefit from a reduction in lost revenues that now occur when the grid experiences high congestion or unplanned outages. Greatly improved restoration times will also provide these stakeholders with economic benefits. Consumers will benefit from more efficient energy markets. More efficient operation will reduce electrical losses and maintenance costs.

Benefits

Implementing a self-healing grid provides benefits to consumers, utilities, and employers. The following list is representative of the types of gains that may occur.

Improved Reliability - Resolving the gaps noted previously will enable a substantial improvement in grid reliability. The cost of power disturbances to the U.S. economy is significant (on the order of $100 billion). The savings from a massive blackout is estimated on the order of $10 billion per event. The 2003 blackout in the northeast is estimated to have resulted in over $50 billion in losses. Since blackout events are increasing in frequency, it is not unreasonable to assume another one will occur within a few years.

Improved Security - A self-healing grid is almost, by definition, the most secure grid. A grid that self-heals is a less attractive target since its resiliency reduces the impact an attack can inflict. Also, the consequences of an attack are reduced because energy sources are distributed, and self-healing technologies can restore service during and after an attack.

Safety - Increased public safety will be a benefit of the modern grid. Grid re-configurations will quickly de-energize downed wires. Restoring power faster to more people will reduce the impact to customers who rely on the grid for medical necessities as well as maintaining HVAC to elder care facilities. Also, fewer outages reduce the opportunities for criminal acts and civil disturbances (i.e., looting).

New Revenue - The installation of DER and DR will create peak shaving and the accumulation of reserves. Both are commercial products in the energy market that can produce revenue streams for their owners.

Quality - The self-healing grid will detect and correct power quality issues. Power quality issues represent another large cost to society, estimated to be in the tens of billions of dollars. In addition, the quality of decisions will improve, and autonomous control will occur more quickly.

Environmental - The self-healing grid will accommodate multiple green resources, both distributed and centralized, resulting in substantial reductions in emissions. In addition, the environmental impact associated with outages and major equipment failures will be dramatically reduced. And a more efficient grid means lower electrical losses.

Chapter 2
Motivates and Includes the Consumer

The second characteristic of the smart grid is a grid that "motivates and includes the consumer". The premise of this characteristic is,

In the modern grid, consumers will be an integral part of the electric power system.

Consumers will help balance supply and demand and ensure reliability by modifying the way they use and purchase electricity. These modifications will come because of consumers having choices that will motivate different purchasing patterns and behavior. These choices will involve new technologies, new information about their electricity use, and new forms of electricity pricing and incentives.

From the modern grid's perspective, consumer demand, or electric load, is simply another manageable resource, like power generation, grid capacity and energy storage. From the consumer's perspective, electric consumption is an economic choice that recognizes both the variable cost of electricity and its value to the consumer under a range of times, places, and circumstances.

Consumers with choices in how they purchase and use energy will be able to:

1. Use price signals and other economic incentives to decide when to purchase electricity, and whether to produce or store it using a distributed energy resource (DER).

2. Purchase "intelligent load" end-use devices that consume power wisely and that become integral parts of the grid to help optimize its operations and reliability.

Each of these choices have proven to provide benefits. The technologies that enable each, such as advanced metering, smart thermostats and appliances, distributed generation, and energy storage, have been demonstrated to give utilities, system operators, retail marketers, electricity consumers and policy makers new tools for achieving their objectives.

The benefits of enabling the consumer to take a greater role are tangible and significant. For example, clipping the spikes of peak demand reduces the need to build new facilities, improves the utilization of existing plants and improves the environment by allowing the retirement or reduced use of inefficient generation.

Peak management activities also support a more efficient marketplace by acting as a dampening factor on wholesale electricity prices, which all consumers ultimately pay. In doing so, they help limit the amount of market power that electricity producers and sellers can exercise.

Environmental benefits also accrue because emissions, worse during peak demands, are substantially avoided.

As a result of these benefits being available, and customers taking actions to obtain them, the modern grid will be a more dynamic system where customer's actions will be an integral part.

Current State

In today's environment, most consumers are fully insulated from the volatility of wholesale electricity markets and the true underlying moment-to-moment cost to produce and deliver the electricity they consume. They purchase electricity under fixed, time-invariant prices that are set months or years ahead. The costs of generating that electricity, however, vary substantially from hour to hour, often by a factor of ten within a single day.

Today there are new opportunities emerging that provide the consumer with better information on the actual cost of electricity. They also present a monetary incentive for consumers to modify their usage in response to that information.

> **Demand Response** (DR) is consumer actions to reduce demand via control of appliances in the home.

These opportunities are primarily related to *demand response* (DR). Examples of DR are time-based or dynamic pricing options where the price of the electricity purchased by a consumer varies by time-of-day. Other examples are programs offered by utilities where customers are paid to curtail or cut back their usage when electric system conditions would benefit. Demand response offerings have been and can be made by utilities, systems operators or third parties such as retail marketers or companies that specialize in demand response technologies and services.

Another area of opportunity is the use of distributed energy resources (DER). This refers to the use of generation systems that are on the customer side of the meter and which can be operated at times of the customer's choosing as an alternative to taking electricity off the grid.

Future State

The future will see a robust and widespread link between energy consumers and the modern grid's operators. Creating this linkage will allow consumers to make informed consumption choices, which in turn will benefit both the consumer and utilities.

As technology improves and new policies allow or even encourage increased deployment, the number of customers actively participating will increase and costs will drop. DR and DER programs and market-based offerings will become even more attractive to consumers.

Achieving this customer participation means making it easy and understandable. And essential to this will be providing a user interface that successfully motivates and supports customer action.

These interfaces can take a variety of forms, depending on the sophistication and desires of the consumer. They could range from a series of simple indicator/warning lights to detailed computer-generated displays of energy and pricing information. Today's communications and electronic technologies create options that were just not viable in the past. Smart Thermostats are an integral component of these concepts.

One example of a future architecture is shown in Figure 1, below. In this example, which visualizes the broad implementation of real time pricing, the mechanism to provide consumers with greater choice involves the insertion of a gateway unit between the energy company and the consumer's appliances. This gateway provides load control based on the consumer's pre-programmed price preferences. In a sense, the gateway acts here as the consumer's agent. New technologies such as computer agents to support consumer decisions and broadband over power lines (BPL) to communicate pricing and other information will enable more effective interaction between the energy company and the consumer.

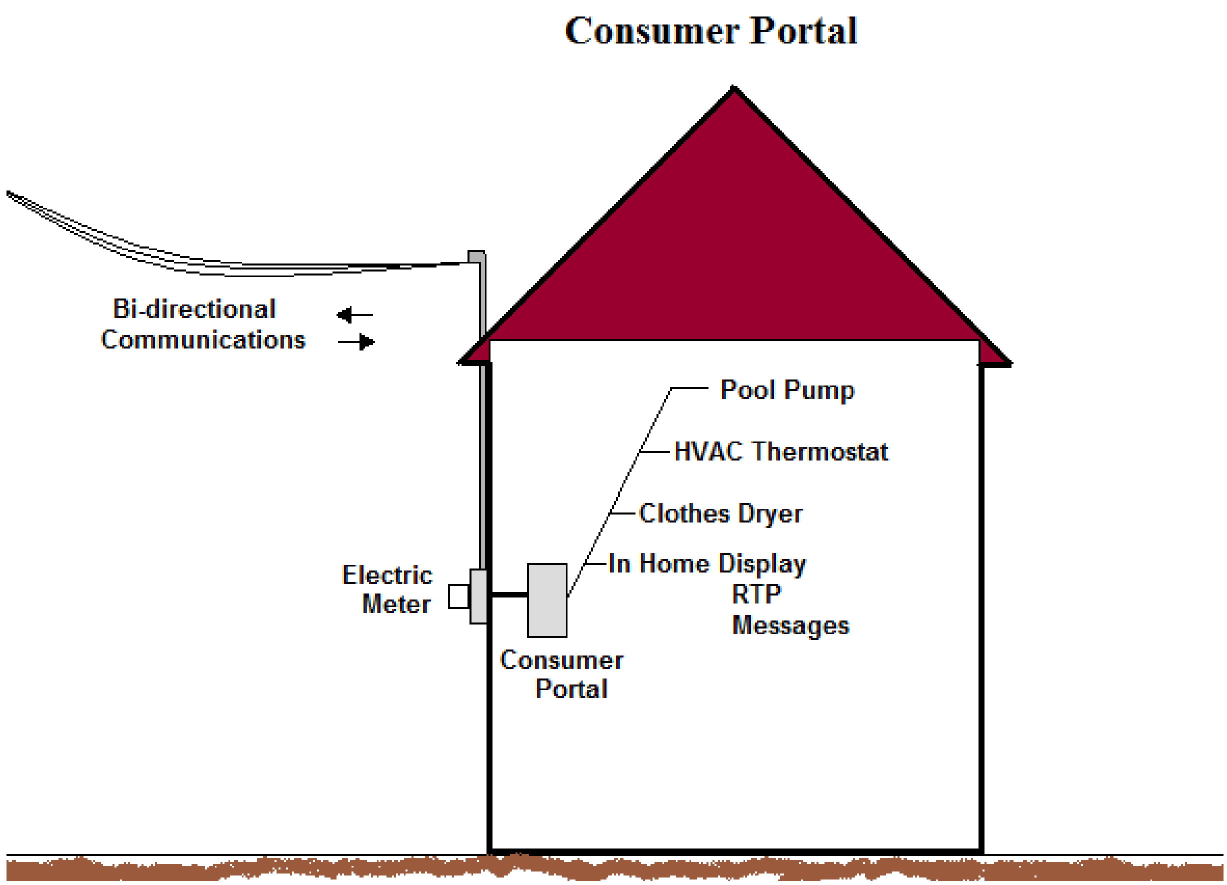


Figure 1

Motivated by economic incentives, consumers will adopt newly available smart appliances. Such appliances will monitor electrical conditions such as voltage and frequency, and automatically turn on or off to support the stability of the grid. Some will also automatically respond to price signals. Distributed resources, another enabling technology, will further strengthen and expand consumers' support of grid operations. Today's digital revolution will seed the needed advances in metering, communications, and decision support.

The modern grid must address the consumer's primary objectives. Whether that is simply lowering the electrical bill at home or enhancing the productivity of manufacturing with cheaper, higher quality or more reliable energy, the overarching requirement is the same: choices and tools that are easy to understand and operate - even to the extent of being automatic.

Most electricity customers, except some large businesses, do not want to become buyers and sellers of electricity - their main pursuit is economical and reliable electricity that can yield for them the true values they seek. An energy management program that operates in the background, quietly providing the quality, reliability and economics sought by the consumer is an example of solutions that can meet these customer desires and needs.

The modern grid must therefore strive to incorporate the consumer into grid operations in an automatic and cost-effective way. The system must have features that; perform consistently within the rules, regulations and agreements between the utility and the consumer, provide power and/or reduce load when needed or desired, and deliver cost savings over time.

Consumer programs such as DR and DER must be cost effective to be successful. Lowering the costs of the required components - such as meters, communications, and central support - is achievable only in mass quantity production. With sufficient consumer interest, the market itself would then support the required production scale needed to make these systems pay for themselves. Simple applications, such as a smart phone app enables consumers to have visibility into their usage patterns.

There are several key components of the modern grid that are required to enable greater consumer choice in energy consumption and to link the consumer into the electricity practices of the grid:

- Consumer applications that are reliable, easy to use and tamper resistant.
- Software applications for the consumer that respond to pricing signals from the utility - this agent software automatically manages the consumer’s usage based on price and within boundaries established by the consumer in concert with the utility.
- Smart communicating meters that measure both consumer usage and grid conditions to help the utility provide desired service at minimum cost.
- The communications infrastructure and control systems to support two-way information flow and load management.
- Processes, tariffs, and incentive programs that serve both the utility and consumer.

Using these systems to the full benefit of consumers and the grid requires semi-autonomous processes and programs that enable both consumers and utilities to share the benefits of grid efficiencies, new pricing regimens, enabling consumer choice and planning as well as acceptable utility returns, grid-friendly appliances that consumers can be encouraged to deploy, and multiple, affordable choices for consumer-usable DER.

Benefits

The economic ripple effect of giving consumers informed choices will benefit all sectors of society. Demand Response has enjoyed considerable progress in overcoming the barriers of regulation and consumer education.

DR projects that included consumers have already produced positive results. Studies have found,

- Participants respond to peak period prices - Overall demand reduced by up to 20 percent with small changes in behavior.

- Participants saved money - Approximately 15 percent for the first two years of the program.

- Participants of all incomes benefited - Low-income households especially respond pro-actively to high prices.

- The meters were not expensive.

- Participants developed better understanding and attitudes about energy usage.

Consumers may represent the largest market for DER well into the next decade as they use it to save money and improve reliability. Deployment of DER will benefit the entire value chain of consumers - commercial, industrial, and residential. Simple connections to the grid will accelerate consumer usage of small generation and storage devices and pave the way for larger ones.

Allowing the consumer to store and generate electricity in a coordinated way can support the grid by lowering the risk of load imbalances, providing quality power for digital devices, regardless of local area fluctuations, and providing a wide range of economic and environmental benefits.

Chapter 3
Resists Attack

The energy industry's assets and systems were not designed to handle extensive, well-organized acts of terrorism aimed at key elements. However, it is critical for the modern grid to address security, making security a requirement for all the elements of the grid and ensuring an integrated and balanced approach across the system. The premise of this section is,

In the modern grid security will be a requirement for all the elements of the grid and a system view that enables an integrated and balanced approach will be used to ensure grid security.

The U.S. energy system is a huge network of electric generating facilities and transmission lines, natural gas pipelines, oil refineries and pipelines, and coal mines. Occasionally, these systems have been tested by large-scale natural disasters such as hurricanes and earthquakes. Generally, industries have restored energy relatively quickly. Sabotage of individual components has caused some problems, but the impacts have been managed.

Photo Courtesy Department of Energy

The dependence of the U.S. economy on the electric system is apparent when millisecond outages disrupt sensitive digital processes, and outages extending days or weeks can deprive a community or region of running water. Telecommunications, financial, and health sectors try to ensure uninterrupted power by installing generators, batteries, or redundant systems. Even these, however, can be limited in their effectiveness. Generators, for example, are limited by the availability of fuel.

Threats to the infrastructure are usually broken into two categories: physical attacks and cyber-attacks. Whatever the specific nature of the threat, the designers of the modern grid should plan for a dedicated, well-planned, and simultaneous attack against several parts of the system. Whether it is going to be a physical or cyber-attack, the modern grid must resist two different attack strategies: Attacks on the power system, in which the infrastructure itself is the primary target, and attacks through the power system, in which attackers take advantage of power system networks to affect other infrastructure systems, such as telecommunications, financial, or government.

Current State

The complexity of the current electrical power system and the reliance on critical nodes to operate without interruption create the potential for single-point failures that can result in widespread disruptions.

In today's grid, failure of a critical node may not be detected or corrected in time to avoid a major disruption. The weak link might become apparent on a hot summer day with specific power flow conditions as the potential catalyst for a widespread blackout, like one experienced on August 14, 2003.

The grid is aging, based largely on technology developed in the 1950s or earlier. This aging infrastructure is stressed by lack of adequate investment to meet the growing demand for electric power.

Ironically, recent advances in technology and changes in the electricity sector, such as deregulation and dependence on 20th century technologies, may be adding to the security problem. Examples include:

- Increased reliance on unprotected telecommunications networks and on associated SCADA systems.

- The growth of independent power producers.

- Outsourcing of maintenance and security by larger companies.

Attacks on the grid could be aided by today's easy accessibility to open sources of information. In the electric power industry, industry publications, maps and material are all available on the internet. These are sufficient to allow someone to identify the most heavily loaded transmission lines and the most critical substations in the power grid.

Hackers could gain access to "open" electric power control systems, crack passwords, and lower protective relay settings, causing circuit breakers to "trip" at normal current flow. They could raise, at the same time, the settings on neighboring circuit breakers so that diverted power would damage the infrastructure protected by those breakers. This happen in the Ukraine in 2015. See the insert on the right.

> "In December 2015, a first-of-its-kind cyber-attack cut the lights to 225,000 people in western Ukraine, with hackers also sabotaging power distribution equipment, complicating attempts to restore power. Ukrainian security services blamed that attack on Russia." - Reuters

Threats to the security of the grid's cyber backbone are increasing. Application of existing security technologies, such as encryption and the widespread use of routine security procedures could help somewhat. However, too many control devices in use on today's grid do not have the bandwidth and processing power to use even the current state of the art in cyber protection.

Future State

The modern grid will address critical security issues from the outset, making security a requirement for all the elements of the grid and adopting a system view that enables an integrated and balanced approach.

Planning for manmade threats will consider not only single, but also multiple points of failure. Parts of the system will need more risk reduction than others. With a system view, security decisions will be based on prioritized options to reduce risk.

Security will benefit from key modern grid technologies that include:

- Integrated Communications for real-time information & control.
- Sensing & Measurement.
- Advanced Components & Distributed Energy Resources (DER).
- Advanced Control Methods.
- Improved Interfaces & Decision Support.

A modern, more resilient grid will leverage technologies for rapid, wide-area communication of the status of grid components. New control technologies will quicken response to events and easily integrate DER.

Enterprises will focus people and processes on implementing and maintaining security. People with experience assessing risk and designing security in complex systems will help develop and operate the modern grid. Process improvements can provide a substantial benefit at low cost. Additionally, processes for resolution of intercompany and inter-regional issues will be put in place.

In the modern grid, implementing cost-effective options to enhance security will also have positive impacts on reliability and resilience. For example, the data required for computer simulations that provide operators with information to predict disruptions could also be used to identify and mitigate attacks against the grid.

The systems approach to electric power security would identify key vulnerabilities, assess the likelihood of threats, and determine consequences of an attack. The designers of the modern grid can draw on extensive experience developed by the Department of Defense in assessing threats and system vulnerabilities. This approach would apply risk management methods to prioritize the allocation of resources for security. Goals of security programs would include:

- Identification of critical sites and systems.
- Protection of selected sites using surveillance and barriers against physical attack.
- Protection of systems against cyber-attack using information denial.
- Dispersing sites that are high value targets.
- The ability to tolerate a disruption.
- Integration of distributed energy sources and using automated distribution to speed recovery from attack.

Resilience must be built into each element of the system, and the overall system must be designed to deter, detect, respond, and recover from manmade disruptions. For the modern grid to resist attack, it must, reduce the threat of attack by concealing, dispersing, eliminating or reducing single-point failures, reduce the vulnerability of the grid to attack by protecting key assets from physical and cyber-attack, and reduce the consequences of a successful attack by focusing resources on recovery.

Therefore, its system requirements include those that:

- Implement self-healing capabilities.
- Enable “islanding” (the autonomous operation of selected grid elements).
- Provide greater automation, wide area monitoring, and remote control of electric distribution systems.
- Acquire and position spares for key assets.

- Use distributed energy resources.

- Ensure that added equipment and control systems do not create additional opportunities for attack.

- Rapidly respond to impending disruptions with the aid of predictive models and decision support tools.

A systems approach with government and industry teamwork will help the requirements and their costs to be allocated sensibly across the modern grid. Adopting a systems approach encourages balanced investment. Security investments must reinforce the weak links in the grid and avoid the costs of ineffective measures. For example, it does no good for a utility to build fences and hire guards to protect its power plant when an unscreened insider or an outside hacker exploiting unencrypted communications can disable the plant.

Federal, state, and local policies and regulations need to be developed to allow utilities and others in the electricity industry to recoup reasonable costs for security upgrades that are part of the overall system design.

For example, federal guidelines and regulations mandating the accommodation of distributed energy resources (DER) would require an investment from industry. The integration of distributed energy would enhance the reliability of the overall system, regardless of which entity owned and operated the DER.

Benefits

The modern grid will deliver substantial benefits if requirements to increase security are met. Besides improving the modern grid's inherent resilience, there are some unique benefits of the modern grid's characteristic to resist attack. For instance, one benefit is that an attack may be deterred simply because it is believed that such an attack would have little effect. Another benefit is improving the operational readiness of our defense forces by ensuring security-of-supply for electric power.

There are also social and economic impacts of reducing attack related disruptions. For example, minimizing the costs of grid repair and costs associated with lost productivity, minimizing the loss of life associated with a loss of power for extended periods of time, reducing social disruptions, reducing the geographic extent of outages, and improving the recovery time from outages.

Benefits attributable to other characteristics such as power quality and DER also satisfy security needs as well.

Chapter 4
Meet Power Quality Expectations

The fourth characteristic concerns power quality. The premise is,

The modern grid would supply varying grades of power and support variable pricing accordingly.

Power quality, or clean power, deserves focus because of the importance of digital devices that have become the engines of so many industries in today's economy. There is hardly a commercial or industrial facility in the country that would not suffer lost productivity if a serious power quality event impacted its digital environment.

> **Power Quality** (PQ) is loosely defined as reliable power that is free of interruption, and clean power that is free of disturbances.

The level of delivered power quality can range from "standard" to "premium", depending on consumers' requirements. Not all commercial enterprises, and certainly not all residential customers, need the same quality of power.

The grade of delivered power is largely determined by the design of the electrical distribution facilities serving a given customer. Special attention can be devoted to minimizing the effect of perturbations. The cost of these premium features can be included in the electrical service contract.

The modern grid would support the mitigation of power quality events that originate in the transmission and distribution elements of the electrical power system. Its advanced control methods will monitor essential components, enabling rapid diagnosis and precise solutions to any power quality event. In addition, the grid's design will include a focus on the reduction of power quality disturbances arising from lightning, switching surges, line faults and harmonic sources. Its advanced components will apply the latest research in superconductivity, materials, energy storage, and power electronics to improve power quality.

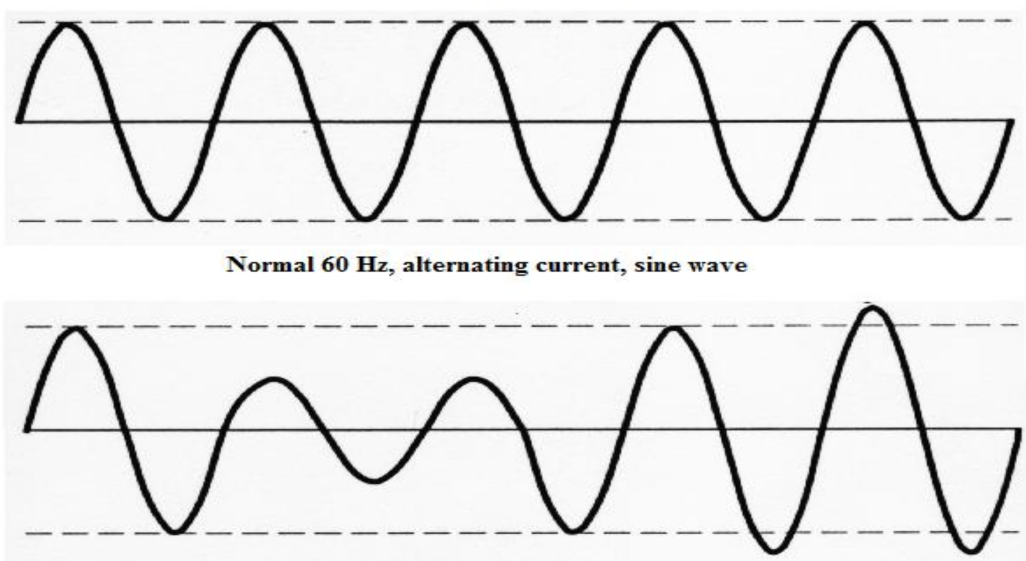
Finally, the modern grid would help buffer the electrical system from irregularities caused by consumer electronic loads. Part of this will be achieved by monitoring and enforcing standards that limit the level of electrical current harmonics a consumer load can produce. Beyond this, the modern grid will employ appropriate filters to prevent harmonic pollution from feeding back into the grid.

The benefits of improved power quality could be tremendous in both cost avoidance and the resulting productivity gains. Clean, reliable power could also produce opportunities for economic growth to areas of the country previously denied the benefits of high-technology industry.

Current State

Voltage sags represent by far the largest power quality issue. Because voltage sags are mostly due to unforeseen and uncontrollable events, the number of voltage sags experienced in the power system varies from year to year. Several industry studies conducted in the last decade provide insight on the number of voltage sags at magnitudes and durations that may occur annually. Power quality is an important issue for the information industry. For example, deciding where to locate power-sensitive server farms depends largely on the availability of clean, reliable power.

Power Quality Description



Normal 60 Hz, alternating current, sine wave

60 Hz, alternating current, sine wave with a transient voltage condition

Figure 2

Power quality is also a large issue for industrial and manufacturing facilities. Tiny power disturbances can wreak havoc with the increasingly complicated, computerized machinery found along assembly lines today. Work stoppages can cost a company up to $500,000 an hour, and power-related problems may cost U.S companies more than $100 billion a year. Studies have shown that power quality disturbances alone cost the US economy between over $25 billion annually. The number of sensitive loads continues to grow, while the costs to minimize power quality events remain relatively high. Clearly, the number of sensitive loads will only continue to grow with advances in communications and information technology.

There exists a large debate as to who should bear the costs of power quality improvement, the utility, or the consumer. The development of new rate structures that offer premium quality has not been universally adopted. Regulatory commissions have not placed a priority on resolving this dispute.

Future State

Advanced technologies deployed by the modern grid will both mitigate power quality events in the power delivery system and protect end users' sensitive electronic equipment.

Because sensitive electronic loads represent an increasing portion of the total power system load, power quality will be of growing importance in the 21st century. Twenty years ago, the amount of electrical load associated with computer chips and automated manufacturing was miniscule. The power system design was well suited to the type of loads that existed then. But ten years ago, the amount of load from chips and automated manufacturing had grown to about 10%. And in the future, it can be expected to grow to more than half. The grid must change to accommodate this changing load characteristic.

The modern grid will be rich with technologies and devices that work at every level of power generation and delivery. These features will contribute to clean and reliable power reaching the consumer. Included among these are:

- Power quality meters.
- System wide power quality monitoring.
- Grid-friendly appliances that control their high-load components, such as compressors and heating elements.
- Premium power programs that include dedicating office parks and neighborhoods to premium power usage.
- Various storage devices, such as Superconducting Magnetic Energy Storage (SMES) and advanced batteries, to improve power quality and stability or to supply facilities needing ultra-clean power.
- A variety of power electronic devices that instantly correct waveform deformities.
- Monitoring of electric system health to identify and correct impending failures that could produce power quality problems.

- New distributed generation devices that can provide clean local power to sensitive loads.

Applying the advanced technologies that mitigate power quality events will require support and coordination among equipment makers, power providers, power users and standards bodies. The resulting design criteria and industry standards must be employed at every level of the electric system, including at the customer's load. This will ensure that the delivered power quality is consistent with the provider's capabilities and the needs of the consumer.

> Commonly, 40% of power quality issues relate to the delivery of power from the utility, and 60% relate to the use of power within an industrial facility.

In the future, the modern grid will price power in accordance with the grade of power required by the user. The level of power quality required by consumers can vary, depending on the complexity of their equipment or criticality of their operations. For instance, a premium power offering holds greater appeal to a semiconductor manufacturer than to a newspaper printer, although both would benefit. Hence, customized premium power packages should be developed to meet these differing industry needs. Not all commercial enterprises, and certainly not all residential customers, need premium power.

The modern grid must apply power quality solutions wherever they are needed — where the power begins, where it gets distributed, or where it ends. Thus, power quality solutions, like the modern grid itself, must be autonomous and distributed. The devices that mitigate power quality events must be spread among transmission and distribution components of the modern grid, but also right at the sensitive load.

Distributing advanced power electronics at each level throughout the grid is a key to solving many power quality problems. Many solutions fall under the broad heading of *Flexible AC Transmission Systems* (FACTS), even though some are deployed on distribution systems.

FACTS and related technologies, including Uninterruptible Power Supplies (UPS), are implemented, and realized through the application of power semiconductor switches applied to high-speed controlled compensation devices. Examples include Static Compensators (STATCOM), Dynamic Voltage Restorers (DVR), and Thyristor Controlled Series Capacitors (TCSC). These FACTS devices may be connected in series and/or in shunt. While the STATCOM is connected at the load end in shunt, devices like the DVR and TCSC, having the capability of eliminating voltage sags and swells as well as rapid adjustment of network impedance, are connected in series with the line. Table 1 below illustrates the application of various power electronic devices.

Table 1
Power Quality Options

Problem	Source Transfer System	UPS	Dynamic Voltage Restorer	Distributed Static Compensator	Adaptive VAR Compensator
Voltage Sags < 50%	√	√	√		
Voltage Sags > 50%	√	√			
Interruptions < 30 sec	√	√			
Interruptions > 30 sec	√	√			
Voltage Flicker				√	√

At the transmission level, voltage sags are frequently the result of faults, which can exist for many milliseconds. In the past, little could be done to reduce this effect. Today, high voltage static VAR compensators (SVCs) are fast enough to mitigate many of these events. However, these devices tend to be quite expensive, partly due to the small numbers deployed and due to the cost of today's power electronic components. As component costs drop, these devices will become increasingly attractive to transmission system owners.

Looking toward the future, affordable current-limiting devices will be able to reduce the severity of voltage sags associated with faults. And eventually, lossless superconducting transmission lines will further reduce voltage sag concerns.

At the distribution level, a variety of techniques are available to improve the quality of power delivered to the end customer. Since lightning is a major source of power quality problems, greater use of underground facilities can minimize this contribution.

Creating premium power quality business parks, where sensitive load customers can locate, can also be valuable. These parks can be directly connected by underground feeders from distribution substations. They can be fed by redundant feeders via high-speed source transfer switches, so that when one feeder is perturbed, the other can immediately take over.

The various power electronic devices shown in Table 1 can be deployed in many distribution applications. And distributed generation and storage resources located close to the load, including micro-grids and green power devices, can isolate the consumer from most grid disturbances.

Not all customers are equally impacted by poor quality of power. At one end of the spectrum, an integrated circuit manufacturer will likely incur large losses if a power quality event shuts down or perturbs the process. At the other end of the spectrum, a homeowner may be only inconvenienced when their internet is interrupted for a few minutes.

The power quality solution not only includes technologies that improve and maintain power quality, but also those that make customer loads more tolerant. Within the customer's facility, advanced devices will offer solutions to power quality sensitivity.

There are several ways customers can limit problems with transients in their facilities. It is best to start by selecting equipment that can withstand transients, and by using proper wiring/grounding practices. In addition, there are many spike suppression devices that can protect customer equipment.

Different sets of requirements must be specified to meet the needs for the different categories of customers: commercial/industrial and residential.

Commercial and industrial customers must be able to select the grade of power they need and then design their systems accordingly. Grid power quality mitigation techniques must then be coordinated with the customer's load sensitivity characteristic to prevent power quality events that can lead to plant outages.

Residential customers will also have varying power quality needs, depending on the sophistication of their home electronics. In general, power quality events are more of an inconvenience than an economic burden to this class of customer. But with so many companies now based at home, the impact to the small business economy is not one to be ignored.

There are four broad types of power quality problems that are typically encountered. Voltage sags, harmonics, transients, and voltage imbalances all create problems for electrical equipment. Each of the four power quality problem areas has its own technical solution, and all these solutions will be enabled by the advanced technologies of the modern grid. The modern grid will provide power quality that fully conforms to the customer's design criteria, as defined by industry standards. Both consumers and service providers need a mutually acceptable standard to develop their respective designs.

Current-limiting and FACTS devices will help reduce the severity of voltage sags associated with power system faults. The most direct way to deal with voltage sags is by providing adequate buffering at the load. And for those customers who take advantage of the modern grid's distributed energy resources (DER), local generation could be provided in a variety of forms such as storage devices, micro-turbines, and micro-grids.

Advanced filters will be highly effective in the elimination of harmonic distortion. A series active filter, for example, presents a high impedance path to harmonic currents, thereby preventing them from flowing from the load to the source and vice versa.

In most cases, customer-owned equipment is the source of harmonics. Harmonics originating in customer equipment can also cause power quality problems for other utility customers, as well as to the power delivery system itself. Responsibility for controlling harmonics falls on both the consumer and the utility. The customer is responsible for limiting harmonic currents that interfere with the power system. The utility is responsible for maintaining the quality of the voltage waveform. Since these responsibilities are highly interrelated, guidelines must establish harmonic limits for each party. Technical groups such as IEEE develop these guidelines and they must be enforced by utilities and state commissions.

Service providers will employ several system design strategies to minimize transients.
Proper grounding and shielding, combined with the liberal application of lightning arresters, will minimize lightning-related spikes. Modern controlled switching techniques will minimize power system switching transients. The use of the modern grid's advanced maintenance techniques - that prevent faults from occurring in the first place - will minimize transients related to power system faults.

While spikes on the grid can be reduced by methods described above, customers can also contribute to the solution. They can limit voltage spike problems in their facilities by selecting equipment that can withstand them and by employing proper wiring, grounding, and surge protection.

In the modern grid, voltage imbalance identification will happen quickly because modern meters will report it to the service provider. Voltage imbalances can cause premature failure of motors and transformers due to overheating and can cause electronic equipment to malfunction. The service provider will normally correct a severe voltage imbalance problem once it is identified.

Carefully chosen and deployed, the key technologies of the modern grid will provide solutions that mitigate these power quality disturbances throughout the system. For instance, the broad deployment of sensing and measurement capabilities of modern meters will provide extensive information regarding the quality of power throughout the grid. This information will be valuable in both resolving problems as they are quickly identified, as well as in the design of grid enhancements and expansions. New sensing techniques will monitor the health of equipment and predict potential failures that can create power quality problems.

Applying the latest research in superconductivity, fault tolerance, storage, and power electronics can improve power quality. Some examples include:

- FACTS and related devices using power electronics.
- Current Limiting Devices using superconductivity.
- Superconducting devices such as synchronous condensers and SMES that improve voltage quality.
- Intelligent switching devices that determine the integrity of a circuit before re-energizing it.
- New clean power distributed resources employed at the local level that isolate loads from grid problems

Advanced control methods will monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event. Advanced control methods are designed to maintain the grid in a stable state at all times and to provide extensive condition information. Proactive prevention of power quality events will be a result of this vast new data base.

Integrated communication will support the new protection and control systems that make the grid more reliable and reduce the occurrence of perturbations that affect power quality. Near real time availability of data allows proactive actions that can prevent equipment deterioration which is another source of power quality problems.

Benefits

Merely avoiding the productivity losses of poor-quality power to commercial and industrial customers can shed billions of dollars of waste from the economy. The costs associated with power quality events at commercial facilities such as banks, data centers, and customer service centers can be tremendous, ranging from thousands to millions of dollars for a single event. The costs to manufacturing facilities can be even higher. Voltage dips that last less than 100 milliseconds can have the same effect on an industrial process as an outage that lasts several minutes or more.

The reduction of power quality problems will produce a proportional reduction in several categories of loss:

- Scrapped materials - This cost can be significant in industries where both the manufacturing process and product quality are extremely dependent on power reliability and quality.

- Customer dissatisfaction - Although difficult to quantify, this factor can create a negative perception that loses clients, revenue, and goodwill.

- Lost productivity - Even if the business shuts down, overhead costs continue and compound the resulting loss of revenue.

- Consumer safety - In some manufacturing processes, such as crane operation in steel production, power perturbations can create safety dangers.

- Contractual violations - Liquidated damage losses and litigation exposures can result from failing to meet specific deadlines.

Intelligently improving power quality in the nation's power system will offer opportunities to broaden and enrich the commercial bases of struggling communities and regions. Rural communities will be able to support clean, high-tech industries that demand high quality and reliable power. New jobs and higher tax bases will transform regions and communities that once depended solely on agriculture or single industries.

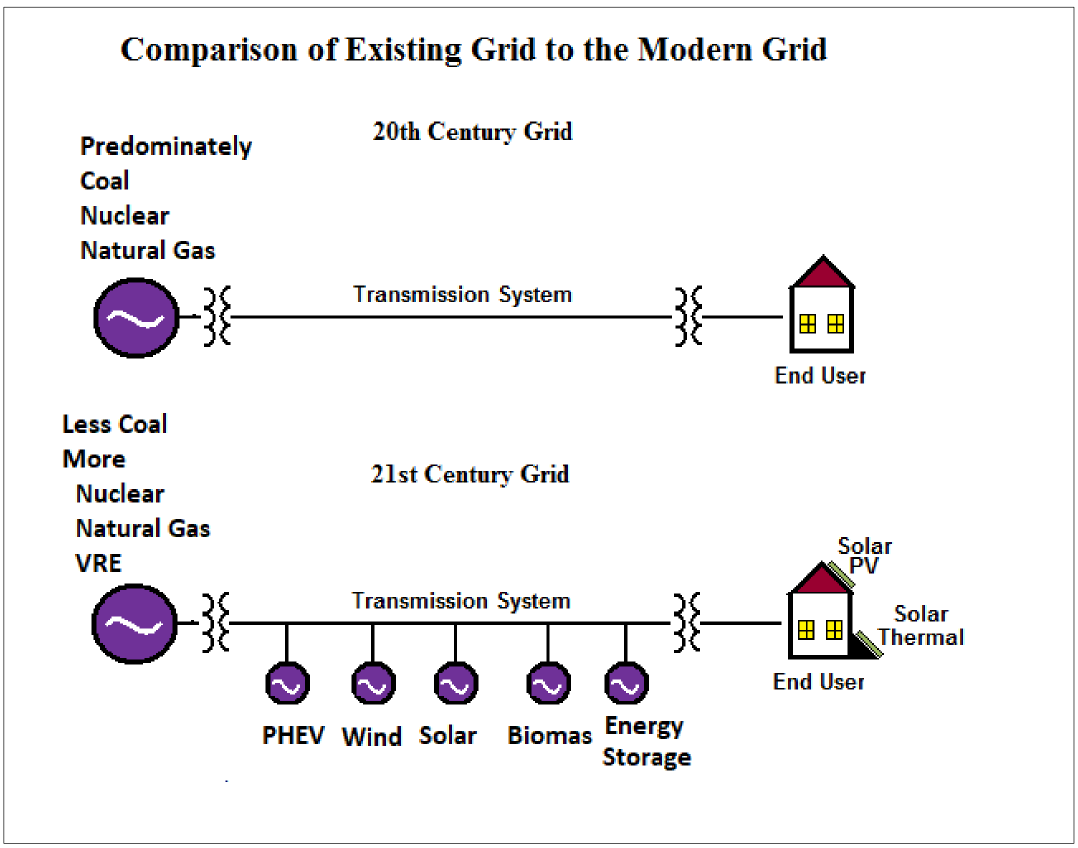
Since poor power quality leads to shorter electrical equipment life and higher electrical losses, economic and environmental benefits also accrue to the utility when power quality is improved.

Chapter 5
Accommodates All Generation Options

The fifth characteristic is that the smart grid will accommodate all generation and energy storage options. The premise is,

The modern grid must accommodate not only large, centralized power plants, but also the growing array of distributed energy resources.

Today, grid-connected distributed generation supplies only 3% of the total energy produced in the U.S. Going forward, DER will increase rapidly all along the value chain, from suppliers to marketers to customers. Those distributed resources will be diverse and widespread, including renewables, distributed generation, and energy storage. Figure 3 is a comparison of the existing grid to the future grid envisioned for the 21st century.



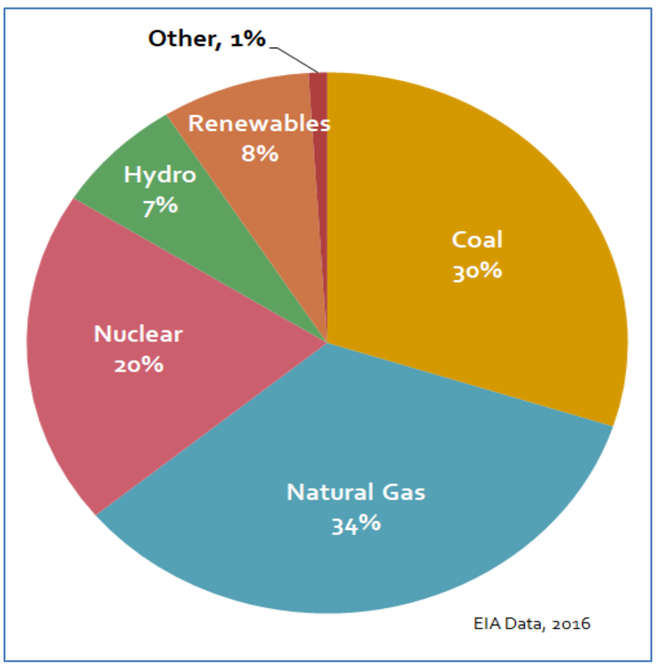
Coping with that diversity will require a host of new and improved functions. Achieving a modern grid will require additional developments in real-time pricing, in smart sensors and controls, in an accepted communications platform, and in advanced tools for planning and operation. It will also require clear standards for interconnection, performance, and metrics.

Barriers exist to accommodating a wide variety of generation. Perhaps the biggest constraint is the slow development of the new functions described above. In addition, the interaction of DER with different distribution networks is not well understood. The total cost of DER is still too high, and consumers have little motivation to invest, limiting deployment to the electric industry itself.

Integrating multiple generation alternatives will provide significant benefits. The result will be a more reliable, secure, efficient power grid. That grid will also be safer, less expensive, and friendlier to the environment.

Current State

A substantial gap exists between existing and desired amounts of DER, particularly in the variable renewable energy (VRE) category. Most of our electricity comes from centralized plants. The U.S. is dominated by big, centralized generating facilities. See Figure 4.



While the mix has changed in the past decade, large generators (coal, nuclear, and hydro) make up over 90% of net generation. Coal use has reduced dramatically along with some reductions in nuclear and natural gas has increased to make up for the shortfall. Variable Renewable energy resources remain a small portion of the total generation at less than 8% of the total. The petroleum and natural gas generation shown does include some small, distributed energy resources and most of this is small reciprocating engines for standby power applications. Combined heat and power (CHP) is the next largest DG component followed by combustion turbines. However, little of that DG is connected to the grid.

Future State

The future offers several growth pathways for DER, depending on how technologies and markets evolve. A modernized grid should be prepared for five likely scenarios, itemized below.

1. DER will increase dramatically

The modern grid must expect and enable a substantial increase in new energy sources. Some States have Renewable Portfolio Standard s(RPS) and other environmental standards that will increase the use of distributed generation. DER is likely to grow rapidly because of cost, regulations, environment, and speed to market.

2. DER will be everywhere

Deployment will occur along the entire value chain. Suppliers will install it. Power marketers will embrace it. And all type of customers – commercial, industrial, residential – will adopt it. The goal should be to expect and enable the same widespread deployment that occurred with personal computers and cell phones.

3. DER will be grid-connected

Standalone generation will continue to be common. But in the future, much more DER will be connected to the grid at many different points – at transmission voltages, at distribution voltages, and at AC and DC networks and microgrids.

4. DER will be aggregated

Both the sources of power and the users of that power will often be aggregated. For instance, wind and solar units may be aggregated into energy "farms" and scattered backup generators into "peaking plants."

5. DER will be diverse

DER will not be dominated by any one size or type of generation. Instead, it will include a wider variety, from those already available to those not yet invented and popularized.

The diversity of distributed energy resources will include sources with a relatively small capacity such as photovoltaic (PV), wind, fuel cells, plug-in hybrid vehicles and energy storage. These devices will typically be connected to low voltage distribution lines or through a DC micro-grid.

Their benefits and affordability will lead to a significant increase in the deployment of DER by consumers. In fact, consumers may represent the largest market well into the next decade as they use distributed generation to save money and improve reliability. But that diversity will include large plants, too. Big power customers and marketers will invest in combined heat and power (CHP) and nonutility generation facilities. Large combustion turbines will be built at a rate consistent with fuel costs and will be located closer to load centers than conventional, centralized power stations.

Looking at what is required to reach the DER goals, it is important to remember that the modern grid must also accommodate new centralized plants. We will need conventional, centralized power stations - coal, oil, gas, nuclear - to meet the increase in demand.

Accommodating a variety of generation options will require a host of new or improved grid functions. This section discusses the importance of generation alternatives and the most essential functions needed to implement those alternatives.

The electric system must accommodate a wider variety of options, often lumped together as *distributed energy resources (DER*). The main options include:

- Distributed generation (DG) – small, widely dispersed plants.
- Renewables – wind, solar, biomass, etc.
- Energy storage – in essence, giant “batteries” and “capacitors”.
- Demand response (DR) – decreasing demand instead of increasing supply in response to peak load.

Photo Courtesy Department of Energy

Renewables such as wind and solar can be either distributed or centralized—from individual, isolated wind turbines, or centralized giant wind farms. DER complements rather than displaces other generation. The 21st-century power system will need a diverse portfolio of generation options.

The market needs services such as real-time pricing, smart controls, communications, planning tools, interconnection standards, performance metrics. Let us look at each of these briefly.

When gasoline prices rise significantly, consumers get clear "price signals" posted on signs outside the filling station. In response, they may look for alternatives, such as conservation, ethanol-based gasoline, and fuel-efficient vehicles. But residential electric customers are not billed on a real-time basis. They receive a monthly bill that charges the same amount whether the electricity was used at expensive (peak) times or low-cost times. Until electric customers get price signals, they will not be motivated to pursue DER.

Tariff features are usually allowed and approved by Public Utility Commissions (PUC), so those entities must re-calculate rate designs with price as a function of time. Then technologies need to get the price signals to consumers, so they can decide.

Providing those signals requires smart meters, information gateways, and technologies that allow transmission and distribution operators to send pricing information. The real-time pricing information will tell suppliers, marketers, DER vendors, and consumers when it makes sense to buy more DER. That investment will in turn spur the development of next generation DER devices, making them even more cost effective.

Integrating DER into the system requires advances in the research and commercialization of smart sensors, protective relays, and control devices. Lower cost sensors and controls will reduce DER installation costs, ensure stable operation of interconnected DER units and safeguard line crews and the public during maintenance and restoration. These devices will be needed even more as autonomous operations increase.

On the customer side of the meter, we need energy-management systems to monitor and control DER operations and demand response requests from the utility.

We need a standard, ubiquitous, integrated communications platform to enable all power system components to intercommunicate. Smart sensors and controls must communicate, but today's grid lacks communications integration and standardization. In most cases, communication does not yet reach to the consumer level. For system operators to integrate new generation sources, communication systems must be able to handle energy price signals and commands.

The lack of a standard platform causes hesitation. Buyers fear their investment will be stranded by technology change. To prevent this, the communications platform of the future must have an open architecture acceptable to vendors, consumers, and utilities. Such a platform will reduce the concern for stranded investments and will stimulate DER deployment.

The modern grid will incorporate generation sources that are smaller, decentralized and often intermittent. But today's operating models cannot reliably operate this new configuration. We require several new tools and technologies:

- New operating models and algorithms to address the transient and steady-state behavior of the modern grid, and the integration of large amounts of DER.
- Improved operator visualization techniques and new training methodologies to enable system operators (both distribution and transmission) to work together to manage systems in both routine and emergency operations.
- Advanced simulation tools that can provide a more complete understanding of grid behavior, especially where many diverse DER units are deployed. These tools are also needed to assist system planners in designing reliable power systems in this new environment.
- Methods for resolving the unique maintenance and operational challenges created by DER, demand response, and other new generation sources.
- Advanced system-planning tools that assess the benefits (and consider the uniqueness) of DER to locate optimal sites for power stations.

Interconnection and operation codes and standards need to be more quickly adopted across the industry to support DER implementation.

The development of these standards will enable DER to be easily integrated with the modern grid - called “plug and play” - to connect any power generation into the grid and communicate fully.

Performance standards and metrics must also be developed. We must ensure that DER owners continuously meet their obligations to grid operators. Regulatory groups should perform periodic audits and enforce compliance when needed. Each owner should perform self-assessments.

Key metrics need to be developed and promulgated to provide the transparency needed to support the safe operation of the modern grid most effectively. Some areas where metrics might be established include: DER percentage of system-wide capacity, energy, and ancillary services, improvements in system and customer reliability, improvements in power quality, improvements in transmission congestion, energy prices, with and without congestion, capital investments and deferred investments, reduction in emissions and other environmental impacts, and reduction in system losses

The new generating sources of DER must be able to do the following: Auto start, load, and shut down in response to price signals and commands from system operators, represent a significant amount of capacity, energy and voltage support on an aggregated, system-wide basis, and integrate safely and reliably with legacy distribution topologies (e.g., long radial feeders) and operations.

One of the most significant impacts on the current state is the advent of microgrids. Evolutionary changes in the regulatory and operational climate of the electric utility industry and the emergence of smaller generating systems such as microturbines has opened new opportunities for on-site power generation by electricity users. When aggregated, distributed energy resources such as photovoltaics, wind generators, fuel cells, microturbines, and other small generation sources can form into virtual power plants. And when coupled with intelligent control systems and directly fed loads they become microgrids. There is significant potential to organize these resources into microgrids to meet both the customer and utility needs.

A ***microgrid*** is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both grid-connected or "island" mode.

The microgrid represents an entirely new approach to integrating DER. Traditional approaches for integrating DER focus on the impacts on grid performance of one, two, or a relatively small number of small sources. Traditionally utilities have required interconnected generators to shut down automatically if problems arise on the grid. By contrast, the microgrid is designed to seamlessly separate or *island* from the grid and reconnect to the grid once the grid is re-stabilized.

At present the electric grid in the United States is composed of three large grids. Microgrids become a "grid within the grid" and create an entirely new approach to how the US electric system is configured. The advantage of microgrids include increased reliability and power quality and increased autonomy with respect to the main grid, offering greater resilience in extreme weather conditions. Microgrids are growing in popularity due to both extreme weather events and the availability of newer equipment, enabling the implementation of intelligent generation, storage, and loads managed by the microgrid controller.

Note that microgrids are not a replacement for traditional utility infrastructure, but instead form a self-contained organization of distributed generation and demand management that is capable of self-balancing when necessary. Individual microgrids may in fact spend most of the time operating in a grid-tied mode, with power flowing both ways between the microgrid and the surrounding system. A parallel bidirectional connection can achieve operational goals, such as improved reliability, cost reduction, and diversification of energy sources. The option to separate from the grid provides a backup or emergency operation mode.

Microgrids may contain elements of other grid-modernization technologies such as renewable generation, demand response, and energy storage, but these are not required for the existence of a microgrid. In most microgrids in which full-time distributed generation has been installed, the solution is based on conventional generators which use local waste fuels, or which operate as cogeneration facilities such as combined heat and power systems. Backup and emergency systems, such as diesel generators in hospitals, may operate in parallel with the grid for the purpose of routine testing. Including reliability and economic applications some of the basic "building blocks" of microgrids may already reside in many networks. A particularly important feature is also to provide multiple end-use needs as heating, cooling, and electricity at the same time since this allows increased energy efficiency due to waste heat utilization for heating, domestic hot water, and cooling purposes.

Benefits

Photo Courtesy Department of Energy

As we overcome the barriers to the modern grid, the seamless integration of diverse generation and storage options will deliver substantial benefits.

Combining power generation and storage options with a modern grid's advanced communication and control systems results in better reliability and power quality: Reduces dependency on the transmission system by strengthening the distribution system, increases operational flexibility during routine, emergency and restoration activities, improves power quality during times of system stress and reduces system restoration time following major events, reduces transmission losses and congestion by locating generation closer to loads, increases "ride-through" capability and momentary voltage support, and reduces the chances for a common mode failure to affect overall operation of the entire grid.

Improvements such as these put us on the road to a "self-healing" grid. In response to signals from system operators and smart sensors, DER will respond in real time with preventive and corrective actions so that reliability issues are avoided or at least mitigated.

The ability of the modern grid to accommodate a wide variety of options can reduce its vulnerability to security attacks and improve its security during major events. Some specific security enhancing features include: Decentralization to the distribution level reduces the grid's vulnerability to a single attack, large quantities of smaller DER, coupled with smaller quantities of large centralized generation, reduce the impact of a unit's failure on overall grid operation, diversity in DER gives operators more choices in response to a security emergency, diversity in a geographic location provides alternate means to restore the grid following a major event, and diversity of fuels at central generating stations (coal, oil, gas, nuclear, hydro) coupled with diversity of fuels at decentralized DER (wind, solar, gas, hydrogen for fuel cells, etc.) increases the probability that adequate fuel supplies will be available.

Accommodating a variety of generation and storage options adds to the modern grid's economic advantages: Eliminates or defers some large capital investments in centralized generating plants, substations, transmission and distribution lines, reducing overall costs by tens of billions of dollars over a 20-year period, enables consumers to participate in the electricity market (and partially fund new generation), reduces peak demand, transmission congestion and peak prices, increases the grid's robustness and efficiency, leading to cost savings and eventual lower rates, encourages retail electricity markets (capacity, energy, ancillary services) and, potentially, emissions markets.

The modern grid is made more efficient by accommodating many generation alternatives including increases options for system planners to address future demand issues, increases options for system operators to improve the utilization of grid assets and improves asset utilization since plants located near load centers reduce transmission losses.

Accommodating generation alternatives is environmentally friendly since it encourages the deployment of smaller DER sources including those based on clean technology, encourages greater use of hydro, solar, and nuclear power that produce zero emissions, and reduces the need for new centralized generating stations and transmission lines.

Finally, the modern grid improves safety, protecting workers and the public. It mitigates the hazards of interconnecting large numbers of diverse generating sources and energy storage devices.

Chapter 6
Enables Markets

The sixth characteristic is that the smart grid enables markets. The premise is,

Correctly designed and operated markets efficiently reveal cost-benefit tradeoffs to consumers by creating an opportunity for competing services to bid.

In general, the fully functioning modern grid will account for all the fundamental dynamics of the value/cost relationship. The challenge for the modern grid is to allow regulators, owners and operators, and consumers to modify the rules of business to suit operating and market conditions. Markets can enable efficient operation under both low stress and high stress conditions. Markets can enable automatic reconfiguration of facilities and equipment as needed to operate reliably and efficiently. Figure 5 shows the differing time frames for market operations and the supporting infrastructure required for those operations.

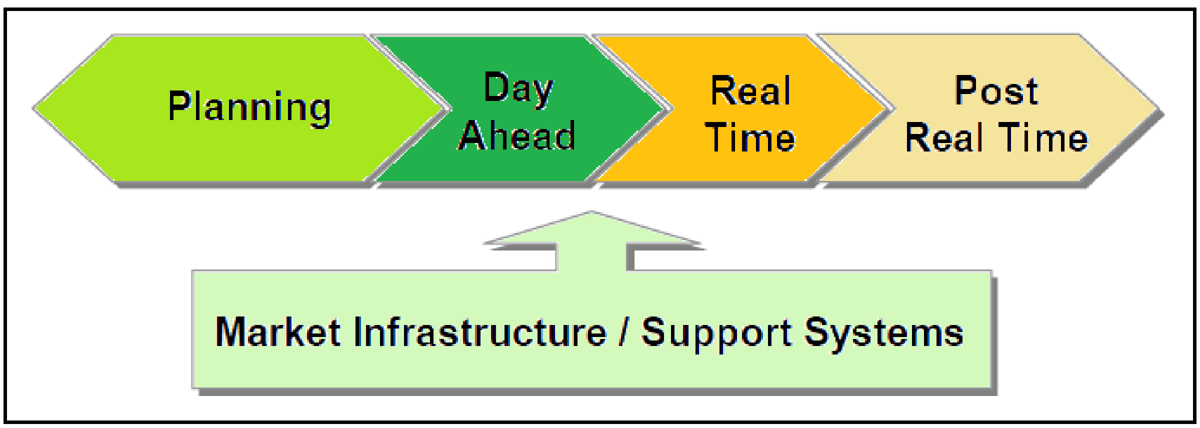


Figure 00

Current State

The nation's electrical power system operates in accordance with rate structures established by the utility's governing body. For Investor Owned Utilities (IOUs) rates are based on expenses plus a reasonable return on investment. Some expenses are passed directly to the consumer. Examples include fuel cost adjustments and power line losses. Retail markets operate in several regions of the nation, governed by state requirements. Retail markets typically separate production costs (cost of generating electricity), and transportation costs (transmission plus distribution expenses.) This transportation expense is sometimes referred to as the "wires" cost.

However, the consumer is served by the same electrical infrastructure (wires) used before the retail choice was enacted, so the cost structure of the wires is the same and is billed as a fixed price-per unit of energy. There are no savings to the consumer from retail choice as far as the wires cost is concerned.

In retail markets, the consumer may choose from a list of producers of electricity. But the production of the energy is also billed as a fixed price-per-unit of energy. Since the competing producers of electricity operate within the same wholesale competitive market, their price variations are minor, or the market would not choose them to produce electricity in the wholesale market in the first place.

Wholesale markets select producers of electricity on an economic merit order, so the least expensive units are selected before more costly units. A constant fixed wires charge plus a production charge which only varies slightly has resulted in a small change in the total consumer energy bill.

The resulting minimal cost savings to consumers is perhaps one reason for low participation rates in the retail choice programs. However, in the wholesale power markets, there is a high degree of variability in the wholesale market hourly prices where a daily high to low hourly price ratio of ten to one is a common occurrence, which makes the wholesale market more attractive.

Experiments in ‘retail choice’ have generally failed due to poorly structured plans and a general lack of interest by consumers. Also, since electricity cannot be stored or ‘saved’ it is not possible to take advantage of pricing differences that are sometimes found in traditional commodity markets.

In contrast to the retail market, the wholesale market operations are operating successfully in several regions of the nation, governed by the FERC in coordination with state utility regulators. The process has four steps:

1. Generators initiate offers to sell their energy to the market and load-serving entities submit bids to purchase it.
2. When a balance is reached between sellers and purchasers, then all loads are served, and the market is declared to be ‘cleared.’
3. Market participants are advised of the ‘cleared’ results to include injection MW, withdrawal MW, hours and prices for each hour thereby initiating their market responsibilities.
4. Settlements occur based upon the bids, offers and actual injections and withdrawals of energy per hour.

Future State

In the future, the scheduling and use of electricity will be fully commoditized by creating open-access markets across the country based on wholesale and retail models. These economically constrained market operations will drive reliability in the grid and open utilities and consumers to new service models that better fit the needs of all grid participants. Electricity markets in the future will integrate many diverse technologies and control functions to include the following:

- Suppliers in the various markets will be seamlessly integrated across all generating unit sizes (from 10kw to 1,300MW).
- Most types of consumers (industrial, commercial, and residential) will participate in the market seamlessly.
- All loads will have some measure of intelligent control, enabling new demand-response (DR) markets.

Regional differences in the transmission level of the electricity network affect the enabling of markets. In the Northeast for example, load is concentrated, so the network is compact. In the Northeast, it may take only 100 miles of transmission line to "touch" one million consumers. In the West, except for major metropolitan areas, load is spread over an expansive geography, so the network must travel long distances between major loads with few lines supporting it. Varied circumstances create varied reliability and economic limitations. In the West, it may take over 1,000 miles of transmission line to "touch" one million customers.

This would suggest that the cost of physically enabling a wholesale market in the West might be ten times that in the Northeast. However, if underground is required, the cost of transmission construction in the Northeast is significantly more costly per mile.

While challenges differ in the West and Northeast, it is equally true for both regions that curbing peak loads and making loads more predictable are common elements of wholesale markets, and all regions will improve in grid reliability through advanced control and protection.

The competitive wholesale market has steadily made more services available to participants, including bilateral transactions, scheduling, day-ahead markets, and reserve sharing. If present trends hold, generation resources of the future will be dispersed throughout the load areas mostly to minimize fuel transportation costs and they will be much smaller in electrical size. This change in generator size-mix over time requires new thought on how to control this vastly distributed resource as well as the impacts in the marketplace.

The future will reveal the need for new market elements. The experiences of the various Regional Transmission Organizations (RTO) and Independent System Operators (ISO) show that participants in the market are active in requesting new services. Specifically, they are requesting, expansion of the ancillary services market offerings, introduction of renewables, carbon trading, and other specialty market, and inclusion of DER market operations and other consumer-rich markets at the wholesale and retail market levels.

There are four basic requirements of electricity markets. They are the existence of an adequate physical and informational infrastructure, sound market rules, vigilant oversight, and fair and equitable access. These four requirements are described below.

1. Adequate infrastructure - Markets can affect load and load can affect network reliability, therefore proper enabling of electricity markets supports a more reliable grid. An efficiently enabled marketplace assumes that the information and control architecture is adequate to provide needed information to appropriate decision makers.
2. Sound market rules - Markets are based on proven principles of physics and economics.
3. Vigilant oversight - In each phase of the electricity market there is independent monitoring and review of operations and participants to assure fairness in the market and reliability of the grid.
4. Fair and equitable access - The foundation of the market is the idea that "it is the same electricity market for all who qualify."

To establish new markets and market services requires the development of new tariffs, systems, information flows in real-time and training for market participants. Therefore, new markets and services must roll out in logical pieces. For example, a market may open with a real time market only and as the market gains experience, later it will open a day-ahead market. An ancillary services market would follow the real time and day-ahead markets.

The seamless architecture of the modern grid can and must extend the electricity market into the electric distribution level. The distribution consumer may participate in demand response (DR) or distributed energy resource (DER) programs which when aggregated, become a market commodity in the wholesale market. While nearly all the distribution systems are operated as state-chartered monopolies, this is the area where the greatest variability in customer needs resides.

To apply DR and DER as market commodities, the modern grid needs to expand current electricity market thinking to include designing for open-access market participation. This expansion of market thinking may take place in the wholesale market, the retail market, a new intermediate market, or some combination of these markets.

Today, FERC regulates interstate wholesale markets and state, and local agencies regulate retail markets. For the modern grid to provide seamlessly integrated markets, it must include interstate wholesale markets, regionally based retail markets, and a new intermediate market that joins them at the distribution level.

Summarized, the design concept must include: Fully effective wholesale markets, selective expansion into retail markets, and new, presently unidentified markets that may not fit the traditional wholesale/retail model.

The design of the modern grid must be consistent enough to enable the electricity market to operate coast-to-coast and deliver economic benefits. In addition, the modern grid requires more sophisticated models to analyze options, refine market performance and design new markets. This includes the planning, day-ahead market, real-time market, post-real-time market time periods.

In the planning time, the following items need to be considered,

- Power systems coordination and planning - Development of strategies that improve overall reliability of the grid and accommodation of future loads.
- Load forecasting - Forecasting of future loads and load profiles across the grid in sufficient detail for power systems coordination and planning.
- Facility and operational data - Developing data integration and acquiring the grid facilities information to support accurate modeling of the grid for planning and operational purposes.
- Long-start resource commitment - Planning that incorporates the long start-up sequence for large, central generation plants into the market operations and reliability coordination of the grid.
- Congestion management - Factoring congested transmission pathways into the planning for current operations, new grid assets, and upgrades.
- Reliability planning and coordination - Establishing operating strategies that implement the performance and planning goals of the grid.
- Generation and transmission outage coordination - Determination of outage impacts and scheduling for the purpose of minimizing challenges to reliability and fair market operations.
- Financial transmission rights (FTR) - Running the forward contracts allocation of FTRs to asset holders and establishing the simultaneous feasibility requirements of the upcoming auction of rights in the market.

In the Day-Ahead market, the following needs to be considered,

- Generation supply offers - The introduction of offers by generators to supply the grid with a specified amount of MW for a specified period at a specified start time, based on an estimated price at a specific grid node.

- Demand bids - The submission of bids to take power from the grid and serve loads of a specified amount of MW for a specified period of time at a specified start time, based on an estimated price at a specific grid node.
- Physical bilateral transactions - A specific agreement between one seller of generation and one buyer of power for serving a load of a specific amount of MW for a specified period at a specified start time for a specified price.
- Financial transactions - A financial hedging function where one party takes control of a specified amount of transmission capacity at a specified grid node for a price; as the transmission service is used by the party or other parties, the difference between the agreed price and the eventual real-time market price is settled.
- Ancillary services - The introduction of offers and submission of bids for spinning reserve requirements, volt/VAR support needs, demand response needs, renewable energy credits, etc.
- Market results - The process by which the electricity market settles the financial commitments made and accepted during the day-ahead market period.
- Re-offer period - A short period at the end of the clearing of the day-ahead market where unfulfilled non–real-time offers and bids can be reintroduced to the electricity market.

The Real-Time market will need to consider,

- Supply offer instructions - The continuous process of sending generating unit production targets to market participants to balance supply and demand at least cost while recognizing current operating conditions.
- Security Constrained Economic Dispatch - An algorithm-based continuous process to simultaneously balance injections and withdrawals at least cost and manage congestion.
- Physical bilateral transactions - The process of executing previously planned bilateral agreements.
- Prices - The continuous process of determining and publishing real-time pricing every 5-minute interval at every commercial node in the electricity grid.
- Re-dispatch - The process of dispatching previously uncommitted (but available) generation to fulfill an emerging demand in real-time at previously set prices or market prices.
- Emergency ancillary services - The process of dispatching available reserves to manage congestion or fulfill a demand that another generator has failed to serve.

The Post Real-Time market will depend on,

- Metering/Meter Data Management Agent - The system where real-time metering data is submitted on behalf of each market participant to the grid operator through a real-time portal.

- Settlement calculations - The performance of a series of computations on received metering data at different post-market day intervals to reconcile supply, demand, and associated pricing in the Day-Ahead, Real-Time, and FTR markets.
- Accounting and billing - The transference of market settlements into individual market participant accounts and creating the appropriate payments and invoices for receivables.
- Settlement disputes - The correction of differences and disagreements in the market results before payments and invoices are made.
- Market auditing - The on-going, independent review of market operations and settlements to assure market fairness and openness.

In addition to the grid infrastructure, the market itself must have suitable infrastructure and support systems. Tagging and scheduling, independent market monitor, FTR functions, LMP and state-estimation functions, contingency functions, and inter-regional communications are just a few of the items to consider in the market design.

The Common Information Model (CIM) architecture is a critical element for standardizing data shared by the various elements of a modern grid. CIM is a necessary foundational element of successful market development because the real-time information important to proper operation comes from hundreds of sources and dozens of entities (transmission owners, generators, market participants, etc.). For example, at MISO, state estimation, location marginal pricing, and network topology depend on commonly used information across more than 30 EMS/SCADA and GIS systems at utilities.

The **Common Information Model** (**CIM**) is an open standard that defines how elements in an IT environment are represented as a common set of objects and relationships between them.

For electricity markets to function properly, near real-time information communication must flow seamlessly between market systems and monitoring and control systems throughout the region. This will require a dispersed, reliable, communications infrastructure.

Voluntary standards must be adopted by federal and state authorities as new law regulates performance of the grid and markets. For example, the Organization for the Advancement of Structured Information Standards (OASIS) has developed standards for business transactions, legal, education and biometric uses. A trusted professional organization such as OASIS must emerge to manage the data protocols of all the energy-related transactions of the new energy market.

Like the real-time operating systems that manage the modern grid, market infrastructure support systems must utilize ISO-certified software solutions as standards to improve the openness, scalability, and maintainability of electricity markets.

Traditionally, the electric grid has been managed by a select few individuals, with little interface between systems and consumers. Energy management systems use interfaces based on the specialized knowledge of grid operators. With the introduction of electricity markets, new users will bring a wide variety of needs, skills, and levels of knowledge. The user interface will require an easier, more socialized interface to accommodate this constituency. This trend will gradually expand as the electricity marketplace is demystified and user interfaces become easy to use in an open-access environment. In time, accessing the modern grid electricity market will be as easy as logging on to eBay or Amazon.com.

Benefits

As barriers are overcome, the infrastructure to enable markets will gradually be implemented and important benefits will accelerate the evolution of the modern grid.

As consumers respond to market data about increases in price, demand will be mitigated. Plus, consumers become more engaged in determining alternate lower cost solutions, which spurs new technology and process development. As consumers suffer interruptions, the load profile and generation profile shift as alternate load management and distributed generation schemes become more prevalent in the industrial, commercial, and residential sectors. These drivers and changes result in fewer and briefer interruptions.

From a marketplace looking for alternate lower cost solutions, the modern grid will be able to offer a wide array of load-management strategies. Distributed generation, energy storage, demand-response strategies, and new ways to effectively manage voltage will emerge to cope with a more volatile operating environment.

Fully enabled electricity markets will also drive smarter decisions about where to locate grid resources. From a system view of the modern grid, it is important for generation siting to have all the related information available to make the best decisions possible.

The modern grid's fully enabled market would open the electricity infrastructure to all consumers, not just transmission owners and independent power producers. Extending electricity market participation to a wider stakeholder group can greatly increase the performance and reliability benefits of a market, whether wholesale or retail. For example, the open access of the cable television industry has greatly expanded services, now providing telephone and internet along with programming selections. Opening access to the electricity markets may result in an expansion of commerce.

Chapter 7
A Systems View of the Modern Grid

The final characteristic of the smart gird is that it optimizes assets and operates efficiently. The premise is,

The modern grid will apply the latest technologies to optimize the use of its assets.

For example, optimized capacity can be attainable with dynamic ratings, which allow assets to be used at greater loads by continuously sensing and rating their capacities.

Maintenance efficiency involves attaining a reliable state of equipment or "optimized condition". This state is attainable with *condition-based maintenance*, which signals the need for equipment maintenance at precisely the right time. Optimized maintenance will be possible when, for example, equipment monitors send a "wear" signal as part of a predictive maintenance regime or a direct malfunction signal in a condition-based maintenance regime.

System control devices can be adjusted to lower losses and eliminate congestion. Operating efficiency is increased by selecting the least cost energy delivery system available through these adjustments of system control devices. Optimized capacity, optimized condition and optimized operations will result in substantial cost reductions.

In the modern grid, asset optimization does not mean that each asset will reach its maximum operating limit. Rather, it means that each asset will integrate well with all other assets to maximize function while reducing cost. For example, load-sharing would routinely adjust the loads of transformers or lighten loads of transmission line sections.

Key technologies to be applied by the modern grid will provide the infrastructure, processes, and devices to support both these examples of optimized asset utilization and maintenance, plus many more.

Current State

In today's grid, the data systems to ascertain real-time asset utilization are not typically available. The current utilization rate of assets within a utility is mostly limited to transformers and transmission lines.

Operators only know the condition of equipment when they perform maintenance or when failures occur. For example, after a maintenance overhaul, they assume that the equipment has been refurbished to an almost new condition. Unfortunately, data systems to support better assessments of equipment conditions are not common, and data mining tools and wear algorithms are rare.

Predictive maintenance, which applies condition-based algorithms to predict future failures and signal the need for maintenance, is not commonly used by utilities.

More commonly, equipment maintenance occurs on a regular time interval or sometimes by diagnostic testing. Regular time interval maintenance is called preventative maintenance, whereas diagnostic maintenance involves performing a health checkup with limited testing on a regular basis.

Diagnostic testing requires taking equipment out of service. Key components are tested and, if all tests show positive results, the equipment goes back in service. If problems are found, then corrective maintenance occurs prior to restoring the equipment. Critical technology tools to optimize assets and their maintenance are not widely used. A great number of sensors are in the marketplace, usually targeted at the transformers and circuit breakers. Nevertheless, many equipment types remain without the sensors to gather needed data for wear algorithms to process.

Probabilistic Risk Assessment (PRA) is presently only used in the nuclear sector of the electric utility industry. Current research offers ways to show a PRA presentation of overloads, voltage violations, and voltage stability warnings for Regional Transmission Organizations (RTO). Grid operations would benefit greatly from this kind of information, but widespread acceptance and implementation has yet to occur.

Future State

The future state of optimizing assets and operating efficiently would include the widespread installation of sensors to provide equipment condition in real-time. This information may be gathered as a direct reading, as with a vibration monitor or as a derived estimation using a wear algorithm. Automated analysis, such as comparing the wear to a threshold value, would signal an exceeded threshold to the asset manager. The asset manager would then perform maintenance, no sooner than necessary.

Using Common Information Model (CIM), Substation Automation (SA), and sensors with widespread communications enables “just-in-time” maintenance. These key technology tools help to accurately gather and transmit the required data to a processing center to develop an equipment maintenance condition status. Only those equipment units in immediate need of maintenance would have maintenance crews dispatched.

In operating the modern grid, optimization can occur when generation resources identify untapped capacity, thus avoiding the startup of more costly generator resources. Dynamic real-time data reveals when and where unused capacity is available. Finding and using that excess capacity avoids the cost of starting up more costly generation. The use of excess capacity also applies to transformers, transmission lines, and distribution lines. For example, avoiding the startup of a residentially placed Distributed Energy Resource (DER) on a cold winter night could be possible if the distribution system could carry the heavy load from the substation.

As modern grid sensors provide more data, asset planning is also optimized. The optimization in planning occurs in the selection and timing of the installation of new assets. Using the data from all grid sensors, planners can decide more economically when, where, what, and how to invest in modern grid improvements.

Moving from the current state to the future state of optimizing assets and operating efficiently requires employing technologies at several levels in the modern grid. In the modern grid, the approach to asset utilization requires gathering the data for processing by the optimization applications and distributing the data widely in real-time. To accomplish these two functions, sensors must first be installed at the equipment and messages must be sent when defects or trends are discovered.

Asset managers would analyze high-risk areas and even individual pieces of equipment for immediate or contingency action. As new real-time information updates the model, operators of the grid will have advanced visualizations depicting congestion areas, probable equipment failures, and the potential consequences. Asset managers will be able to foresee the consequences of maintenance tasks and make informed business decisions.

Gathering useful data and distributing it where and when needed requires the use of sensors, common information model, widespread communications, and substation automation.

Wide varieties of Intelligent Electronic Devices (IED) sensors already exist for many of the equipment types employed by the modern grid. From a functional basis, the processing can be done locally or remotely, but the preference is to trend results and then to query in near real-time to assess equipment under investigation. Additional sensors will be required to fill in the gaps between what is known about the equipment and what needs to be known about the equipment. Such sensors may include monitors of vibration, chemical analysis, acoustics, temperature, or any of the electrical parameters used in the delivery of electricity.

The Common Information Model (CIM) is a vital ingredient to the data collection from equipment. CIM will be the single most important data validation methodology in place because, by definition, it associates the equipment with the performance criteria to be measured. It thus enables validation of the equipment's quality parameters.

A communications path is required to get data and information from the equipment to the asset manager. Even Supervisory Control and Data Acquisition (SCADA) only cover about half of the substations, so large-scale communications will be required to implement this characteristic of the modern grid.

Substation automation (SA) functionality must be extended to the distribution level. Predictive maintenance routines are greatly enabled by the implementation of a substation automation scheme. Applying substation automation technology more widely would allow monitoring more equipment and expand the base of power quality data.

Substation automation will also provide both a local and remote human-machine interface. In addition, it will provide the ability to consolidate and prescreen data, thus reducing the data load on the communications system between the substation and the operations center.

Substation automation technologies would support wider use of remote cameras to help other elements of the modern grid resist attack. These same cameras can be used to view equipment for visible signs of health (such as infrared imaging and thermography). As asset optimization methods become more widely used, substation data will be sent to more control areas. As a result, the increased observations will reduce the time to estimate status of equipment throughout the grid.

Asset optimization technologies must satisfy requirements at several levels of the electrical power system including the distribution level, operations level, regional transmission organization (RTO), control area level, and planning level.

Asset optimization at the distribution level requires configuring circuits and operating capacities to minimize losses. Such software solutions already exist but are not common in the US.

Asset optimization in operations requires real-time dynamic ratings for both lines and transformers. While lines may have inconsistent temperature environments, average values may apply for the short term. Technologies are required that embed temperature sensors inside the conductor at regular intervals for a complete temperature profile of the line. Transformers should have a temperature sensor in the substation. Operating a transformer closer to its limit could save a re-dispatch of generation, thus increasing efficiency while increasing the utilization of the asset.

Asset optimization at the RTO and control area level requires data to be integrated to show the big picture. Loop flows, or the passing of energy through an area for use by others outside that area, may be avoided by an operating configuration only visible at the RTO level where multiple control area schemes are presented. That configuration may save costly upgrades, enable more economic dispatch, and enable greater asset utilization for all parties.

Planners need to know the options available to optimize asset loading. Maximum demand might be rarely needed. Conversely, it might be urgently needed during an emergency procedure. Having all the data showing different ways to optimize loads would provide planners with the details to manage assets more flexibly and effectively.

Key technologies applied by the modern grid will help close the gaps between the grid's current and future states. The modern grid infrastructure will be required to integrate both applications and device technologies.

Real-time dynamic rating applications will allow existing assets to be used at greater loads under certain conditions. Since heat is a limiting factor in the operation of electrical equipment, heat-mitigating conditions such as cold weather or elevated wind may offer increased capacity during windows of opportunity.

Probabilistic Risk Assessment (PRA) assists in operations and maintenance decisions because asset managers can know the probability of failure of their assets. However, unless they understand the consequences of that failure, the true risk is hidden. A PRA combines the probability of failure and the consequences of that failure to arrive at a real-risk factor.

PRA assists in planning decisions because planning managers often know the consequences of an asset failure, but few may know the probability of failure of their assets. As with maintenance and operations, a PRA combines the probability of failure and the consequences of that failure to arrive at a real-risk factor. Using true risk probabilities, the planner will have more information to arrive at more informed decisions.

The CIM ties the identification of equipment to its measurements. There are six different CIM categories: wires, SCADA, load, energy scheduling, generation, and finance. Each category has specialized formats to encompass the information being transmitted. The requirement is that CIM be adopted as the industry standard and fully integrated into the modern grid.

Failure rate analyses collect data about known equipment failures. Failure rate data includes the asset nameplate information, the failed component, the cause of failed component, utilization history, operating cycle, percent loading, environment, and location. The analyses by themselves can become a performance indicator and improvement tool.

Root-cause analysis of failure rates may provide insights to solutions to eliminate failure altogether. It requires a great deal of information to perform failure rate analyses. Filling the gaps between sensors, communications, and condition-based monitoring systems will enable this analysis to be automated and thus cost-effective.

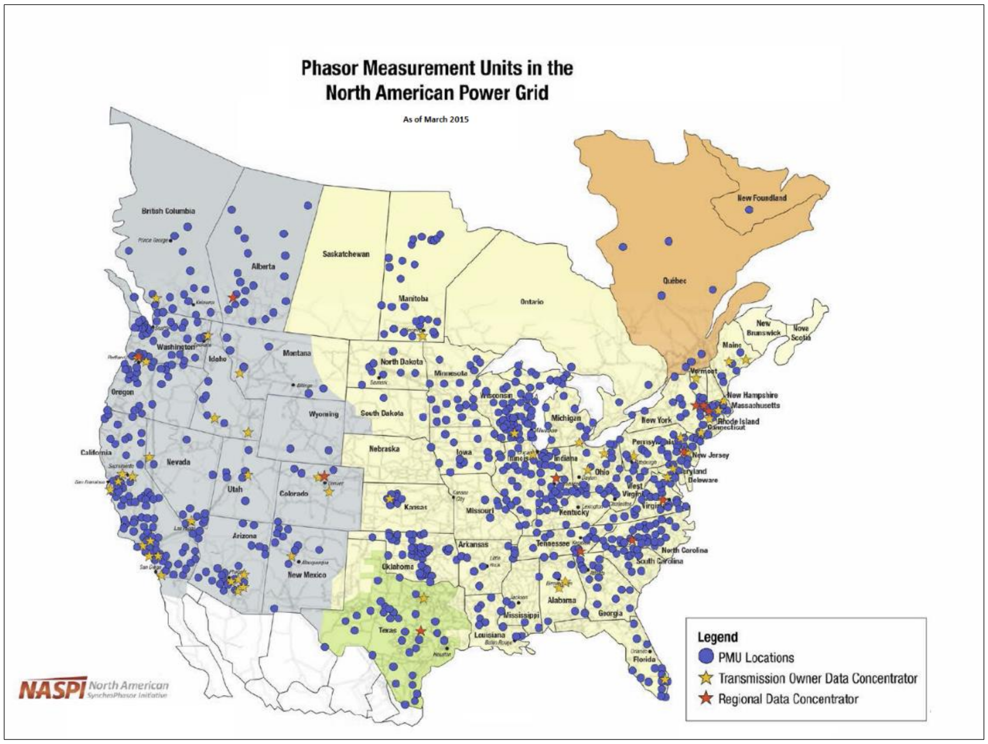
Both condition-based maintenance and predictive-maintenance methodologies are dependent on meeting requirements for sensors and communications technologies. Software presently exists for detailed analysis and presentation applications. The solution lies in the implementation of monitoring technology, which will enable a just-in-time maintenance regime.

Advanced monitoring, as applied in substation automation, could be integrated into other levels of the grid as well. Equipment state and parameters could then be viewed in real-time by other control elements of the grid such as central utility headquarters, distribution centers or even other substations.

Courtesy Schweitzer Engineering Laboratories

Advanced monitoring technologies may also provide a needed solution to identifying the precursors to underground cable failure. This identification may lead to the execution of operating guides to reduce the effect of such failures on the grid. Advancements in Phasor Measurement Unit (PMU) technologies provide real-time assessment of grid flows and help to determine whether system stability requires the opening of tie lines.

There are many PMU's in operation in the US today. The map shown in Figure 00 shows the status of PMU installations.



Remotely operated cameras in substations and other grid critical locations can deter or warn of attack. Infrared scans can also offer real-time assessment of local heating of grid elements such as risers, connectors, and bushing terminals, as well as visual observations of transformer-cooling radiator operation.

The installation of IEDs in the substations provides extended protection as their primary function. They also provide a wealth of information available by the simple connection to a communications port.

The grid can use a variety of existing sensors to implement many of the applications required to enable a full asset optimization program. These sensors include relay IEDs, oil pump monitors, vibration monitors, thermometers, pressure gauges, and specific gas detectors, to name just a few. There are some missing sensors in the sensor family, mostly due to cost or choice of maintenance policy. A low-cost combustible gas analyzer would be an example of a sensor to yield real-time data.

Widespread communications infrastructure to all substations and distribution switch locations has not occurred. Communication types include telephone, fiber optics, microwave, cellular, and broadband over power line carrier (BPL).

Benefits

The benefits of optimizing assets and operating efficiently can be viewed in the context of the modern grid's key success factors.

The use of advanced monitoring technologies will provide the information for asset management programs to realize substantial cost savings through improvements in reliability. The detailed awareness of component and equipment condition reduces human errors in performing maintenance and helps to avoid outages for unnecessary maintenance.

A security benefit resides in substation automation with the installation of low-cost remote cameras that can monitor equipment. This function can be scaled to other grid elements.

Asset optimization has the opportunity for gaining economic benefits because greater power densities can be attained using the same existing assets. In an energy market, this increase in utilization increases revenue for the asset owner, and at the same time lowers energy costs for load-serving entities. This win-win scenario offers economic incentive to both asset owners and users of energy.

Modern grid assets will remain in service longer and have a lower maintenance profile, thus attaining higher asset utilization. Asset utilization measures performance, loads carried, and maintenance costs. Heavily loaded assets that perform for long times with little maintenance are best utilized.

Optimizing maintenance programs should result in performing less maintenance. Less maintenance work equates to less exposure to accident and thus increased safety to maintenance personnel.

Summary

We have just reviewed the seven broadly defined characteristics of a new, modern, smart, grid for the electric utility industry. Using these characteristics as a guideline – and moving to the future vision for each characteristic – should enable the present electric grid to transition to the modern grid. Once attained, the modern grid will be more reliable, more secure, more economic, more environmentally friendly, and safer. This transaction will take time – and money – to accomplish, but it holds promise of continuing to be the backbone of the economic system in the United States.

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