The NETL Modern Grid Initiative

A SYSTEMS VIEW OF THE MODERN GRID

Conducted by the National Energy Technology Laboratory
for the U.S. Department of Energy
Office of Electricity Delivery and Energy Reliability
January 2007

Office of Electricity
Delivery and Energy
Reliability

V2.0

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Utility and technology experts agree that there's an urgent need for major improvements in the nation's power delivery system. The change to a fully modern grid must meet increasingly higher standards in reliability, security, cost of service, power quality, efficiency, environmental impact and safety.

To meet those higher standards, we have confronted some tough questions: What performance do we expect from the modern grid? How would it be characterized to meet those expectations? What technologies must be brought to bear? And how do we know if we're succeeding?

This document explains our approach to answering these questions. We frame this approach with a *systems view*. This systems view contemplates the desired grid using five interdependent primary elements. (See Figure 1).

Figure 1: A Systems View of the Modern Grid provides an "ecosystem" perspective that steers a direct approach to a total system solution.

Key success factors determine how the grid must perform. These factors establish the foundation of success, around which the other four elements must interact. The **performance** required of the grid dictates its desired **characteristics**. These characteristics determine which **technologies** to use. **Metrics** gauge success and tell us how to fine-tune the performance requirements. With such a perspective, we can address root issues and structure a total solution, instead of piecemeal patches.

The primary elements of the modern grid's systems view are described in the five major sections of this document:

- **Key Success Factors** – The broad goals of the modern grid.
- **Performance** – What the grid must do to succeed.

- **Principal Characteristics** – What features and functions are essential to meeting performance requirements.
- **Key Technology Areas** – Which technologies support the desired characteristics.
- **Metrics** – How progress is measured and compared to the desired level of performance, to ensure that the key success factors are ultimately achieved.

One of the weaknesses in marshalling a coordinated approach to modernizing the electric grid has been the lack of a clear understanding of the electric system's driving forces and levers for change. With the systems view of the modern grid, the NETL Modern Grid Initiative (MGI) team has provided the framework for moving forward. This document ends with a call to action for all those who wish to participate in making the modern grid a reality.

Additional related documents prepared by the NETL MGI team are also identified. These documents provide more detail on each of the modern grid's principal characteristics and key technology areas, describe the motivating factors for a modern grid, and the planning underway by the NETL MGI team.

Creating the Systems View

A modern grid is a necessary enabler of a successful society. The fundamental driver behind the modern grid initiative is the recognition of electric power's essential societal role.

But today's grid is being operated in ways beyond its design, such as unpredictable power transfers over long distances. The grid faces current delivery constraints because of limited transmission, resource availability and future emissions requirements. Natural disasters may place additional stresses on grid operations that are difficult to predict today,

The NETL Modern Grid Initiative team held industry-wide discussions across the country to describe the systems view approach and to advance the changes needed in the nation's power delivery system. Leaders in government, utilities, regional transmission organizations, consumer and environmental groups, universities and research and development organizations convened at seven separate Modern Grid Regional Summits to validate current thinking and provide new ideas.

The MGI team used the information gathered from these sessions to answer the following questions:

- What is a "modern grid"?
- Why are its characteristics important?
- How do they compare with the characteristics of today's grid?
- What are the gaps between today's grid and the vision of the modern grid?
- What are the enabling technologies and processes that can fill the gaps?
- What programs are already underway to fill the gaps?
- What programs still need to be initiated to fill the gaps?
- What approach to modernizing the grid does this team recommend?

Answers to these questions established a consensus for the five primary elements of the Modern Grid systems view:

- Key success factors
- Performance
- Principal characteristics
- Key technology areas
- Metrics

We explain each of these elements in the following sections.

Systems View Analogy - The difference between a catalog and a novel
One can construct a catalog by gathering many technology data sheets and arranging them in some order, such as alphabetic. However, one does not construct a novel this way, at least, one that makes sense. The novelist starts with an overall vision, constructs a storyline, and builds and integrates the novel pieces in a manner that supports the vision and goals he has

developed. The nation's grid should be modernized in a similar fashion; not by gathering a raft of interesting technologies and calling it modern, or smart, or intelligent, but by first building the construct of a modern grid that serves a defined purpose. The systems view approach was used by the NETL MGI team to develop the construct of a modern grid that serves a defined purpose.

There is value in creating the "grid novel". As the industry begins to modernize the grid, the systems view not only provides a starting point, it also provides checks and balances along the way. As new technologies are introduced, the systems view asks not only "does it work" but also "does it fit" the vision?

Plus, the systems view assists the industry with signposts along this long, difficult journey to modernize the grid. By trending certain **metrics** around **performance** that matters, the industry can see how it is improving with respect to the **key success factors** to serve the consumer and our overall society.

KEY SUCCESS FACTORS

The key success factors for the modern grid establish a basis for specific performance requirements and for measuring progress and benefits. They are rooted in the consensus of stakeholders who agreed on its broad goals.

The key success factors are:

- **Reliable** – A reliable grid provides power dependably, when and where its users need it. It provides ample warning of growing problems and withstands most disturbances without failing. It takes corrective action before users are affected.
- **Secure** – A secure grid withstands physical and cyber attacks without suffering massive blackouts or exorbitant recovery costs. It is less vulnerable to natural disasters.
- **Economic** – An economic grid operates under the basic laws of supply and demand, resulting in fair prices and adequate supplies.
- **Efficient** – An efficient grid takes advantage of investments that lead to cost control, reduced transmission and distribution electrical losses, more efficient power production and lower costs of ownership.
- **Environmentally friendly** – An environmentally friendly grid reduces environmental impacts through initiatives in generation, transmission, distribution, storage and consumption.
- **Safe** – A safe grid does no harm to the public or to grid workers and is sensitive to users who depend on it for life safety.

Key success factors help determine requisite performance, the next primary element.

SPECIFYING THE GRID'S PERFORMANCE REQUIREMENTS

If we want the grid to succeed as described in the previous section, it must meet certain performance standards. Working with its stakeholder partners, the Modern Grid Initiative specified five essential requirements:

- **Emergency response** – A modern grid provides advanced analysis to predict problems before they occur and to assess problems as they develop. This allows steps to be taken to minimize impacts and to respond more effectively.
- **Restoration** – It can take days or weeks to return today's grid to full operation after an emergency. A modern grid can be restored faster and at lower cost as better information, control and communications tools become available to assist operators and field personnel.
- **Routine operations** – With a modern grid, operators can understand the state and trajectory of the grid, provide recommendations for secure operation, and allow appropriate controls to be initiated. They will depend on the help of advanced visualization and control tools, fast simulations and decision support capabilities
- **Optimization** –The modern grid provides advanced tools to understand conditions, evaluate options and exert a wide range of control actions to optimize grid performance from reliability, environmental, efficiency and economic perspectives.
- **System planning** – Grid planners must analyze projected growth in supply and demand to guide their decisions about what to build, when to build and where to build. Modern grid data mining and modeling will provide much more accurate information to answer those questions.

Meeting these performance standards requires a modern grid to include certain important features. These features comprise its **principal characteristics**, the next primary element of the systems view.

ESTABLISHING THE PRINCIPAL CHARACTERISTICS OF THE GRID

The previous section defined the essential performance requirements and the measures of success in progress and benefits. This section explains characteristics of the modern grid and notes their design features and benefits.

Seven principal characteristics comprise the third element of the systems view. They emerge from the first element's key success factors and the second element's performance requirements. In the systems view, the modern grid:

- Self-heals
- Motivates and Includes the consumer
- Resists attack
- Provides power quality for 21st century needs
- Accommodates all generation and storage options
- Enables markets
- Optimizes assets and operates efficiently

In the following sections, we discuss each characteristic and its benefits. Then we summarize them before moving to the fourth element of the systems view — the grid's enabling technologies.

SELF-HEALS

The modern grid will perform continuous self-assessments to detect, analyze, respond to, and as needed, restore grid components or network sections. Self-healing will help maintain grid reliability, security, affordability, power quality and efficiency.

Seven Principal Characteristics of the Modern Grid
Self-heals
Motivates and Includes the consumer
Resists attack
Provides power quality for 21st century needs
Accommodates all generation and storage options
Enables markets
Optimizes assets and operates efficiently

- The self-healing grid will minimize disruption of service, employing technologies that can acquire data, execute decision-support algorithms, avert or limit interruptions and restore service quickly.
- Probabilistic risk assessments based on real-time measurements will identify the equipment, power plants and transmission lines most likely to fail.
- Real-time contingency analyses will determine overall grid health and identify the need for immediate investigation and action.
- Communications with local and remote devices will help analyze faults, low voltage, poor power quality, overloads and other undesirable system conditions. Then appropriate control actions can be taken, based on these analyses.

Design features and functions

- **Resolution time and probabilistic risk assessment** – Threats to electrical service will be identified before problems occur.

- **Power stabilization techniques** – Power stabilization software will look for the early signs of a cascading blackout and automatically mitigate the event faster than humans can react. FACTS (Flexible Alternating Current Transmission System) and WAMS (Wide Area Measurement System) are among the technologies that will help to stabilize the system.
- **Auto-restoration processes** – Distribution circuits will contain new, protection, communications and control elements able to sense circuit parameters, isolate faults, and quickly restore service automatically by employing such tools as feeder ties and distributed resources.

Expected benefits

Reliability and cost savings to consumers and energy suppliers are all benefits of a self-healing modern grid.

- The Customer Average Interruption Duration Index (CAIDI) which measures the average customer outage duration should improve by an order of magnitude. The vast majority of affected consumers should have power restored within five minutes of the service interruption.
- By minimizing or eliminating interruptions, the self-healing grid could save industrial and residential consumers over $100 billion per year. [*Source:* Electric Power Research Institute. 2003. The integrated energy and communication systems architecture: Volume II: Functional requirements. Palo Alto, CA: EPRI]
- Peak shaving and the accumulation of reserves, both of which are commercial products in the energy market, can provide revenue to their owners.

Motivates and Includes the Consumer

Seven Principal Characteristics of the Modern Grid
Self-heals
Motivates and Includes the consumer
Resists attack
Provides power quality for 21st century needs
Accommodates all generation and storage options
Enables markets
Optimizes assets and operates efficiently

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 modern grid, well-informed consumers modify consumption based on the balancing of their demands and the electric system's needs.
- In such an efficiency-fertile environment, demand for new cost-saving and energy-saving products will benefit both the consumer and the power system.
- Demand-response (DR) programs will satisfy a basic consumer need: greater choice in energy purchases. The ability to reduce or shift peak demand allows utilities to minimize capital expenditures and operating expenses while also providing substantial environmental benefits by reducing the need for operating inefficient peaking power plants. Over time, DR will also encourage consumers to replace inefficient end- use devices such as incandescent lighting.

Design features and functions

- **Consumer decision support** – System elements that inform the customer about the cost and value of their consumption in real time
- **Communications infrastructure** – Two-way, real-time communications between the consumer and the service provider.

- **Real-time pricing, power, and use information** – Information, such as patterns of consumption that tell consumers the price of electric energy at any given moment and the environmental nature of the energy being supplied.
- **Semi-autonomous processes and programs (agents)** – Computer programs that act on a consumer's own pre-defined needs.

Expected benefits

Consumer-based demand response projects, for example, have produced positive results for both consumers and the electrical system itself.

A typical demand response case study has shown:

- Participants respond to peak period prices and overall demand is reduced by up to 20% with small changes in their use of energy.
- Participants save money — approximately 15% for the first two years of the program.
- All participants benefit, regardless of income.
- Increased investments in energy efficiency result
- Utilities deliver services and use assets more efficiently.

RESISTS ATTACK

Seven Principal Characteristics of the Modern Grid
Self-heals
Motivates and Includes the consumer
Resists attack
Provides power quality for 21st century needs
Accommodates all generation and storage options
Enables markets
Optimizes assets and operates efficiently

Security requires a system-wide solution that will reduce physical and cyber vulnerabilities and recover rapidly from disruptions.

The modern grid will demonstrate resilience to attack, even from those who are determined and well equipped. Both its design and its operation will minimize the consequences of an attack and speed service restoration.

It will also tolerate 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 will contain elements of deterrence, prevention, detection, response, and mitigation to minimize impact on the grid and the economy. Such security technologies include authorization, authentication, encryption, intrusion detection and the filtering of network traffic and communications.

Design features and functions

- **Identification of threats and vulnerabilities** – Enhanced critical threat information with closer ties between system operators and government.
- **Protecting the network** – Increased cyber attack security of multiple system elements, such as encrypting communication between operations centers and process control systems.
- **Inclusion of security risk in system planning** – Anticipating the effects of a coordinated terrorist attack in system-wide planning.

Expected benefits

System-wide security is dramatically enhanced by applying readily available technologies to the modern grid:

- Reduced system vulnerability to physical or cyber attack.
- Minimal consequences of any disruption, including its extent, duration, or economic impact.
- Using security-related improvements to also help optimize reliability, communications, computing, decision-making support and self-healing.

PROVIDES POWER QUALITY FOR 21ST CENTURY NEEDS

Seven Principal Characteristics of the Modern Grid
Self-heals
Motivates and Includes the consumer
Resists attack
Provides power quality for 21st century needs
Accommodates all generation and storage options
Enables markets
Optimizes assets and operates efficiently

The modern grid will provide the quality of power desired by today's users, as reflected in emerging industry standards.

These demands and standards will drive the grid and consumer to balance load sensitivity and power-quality at a reasonable price.

- Two factors negatively affect power quality.
  - Moving power from generation to the load via distribution systems that introduce harmonics, imbalance, sags and spikes.
  - Distortion of the electrical current wave due to the load's conversion from AC to DC.
- Dirty power slows or stops work that can cost more than $20 billion per year for all U.S. companies. [*Source:* Electric Power Research Institute. 2003. The integrated energy and communication systems architecture: Volume II: Functional requirements. Palo Alto, CA: EPRI]
- The revolution in home electronics means residential consumers will demand better power quality.
- Poor power quality also negatively affects the life expectancy and efficiency of the grid itself. For example, harmonic currents associated with poor power quality produce no useful power yet create electrical losses that must be supplied by increased electrical generation.

Design features and functions

- **Modern procedures and protocols** – Limiting and/or buffering voltage sags and surges on the grid to fully conform to industry standards' design criteria.
- **Transient-suppression** – Modern switching and advanced maintenance that help service providers prevent momentary power fluctuations from reaching users of digital devices.
- **Communicating meters** – Voltage imbalances reported by networked meters to service providers for immediate repair.
- **New industry guidelines** – Established limits on consumer-induced harmonic currents and utility-controlled voltage waveform quality.
- **Reduced PQ sensitivity of loads, including careful attention to wiring and grounding methods**.

Expected benefits

Just avoiding the productivity losses due to low quality of power will benefit the economy by billions of dollars each year.

The business benefits of avoiding productivity losses can take various forms, including:

- Safer manufacturing processes
- Improved consumer satisfaction
- Reduced liability litigation
- Improved sales from better serving customer demands
- Lower production costs by reducing downtime due to power aberrations.

ACCOMMODATES ALL GENERATION AND STORAGE OPTIONS

The modern grid will seamlessly integrate many types of electrical generation and storage systems with a simplified interconnection process analogous to "plug-and-play".

Seven Principal Characteristics of the Modern Grid
Self-heals
Motivates and Includes the consumer
Resists attack
Provides power quality for 21st century needs
Accommodates all generation and storage options
Enables markets
Optimizes assets and operates efficiently

- Improved interconnection standards will enable a wide variety of generation and storage options.
- Flexibility in capacity and interconnected voltages will characterize electricity generation options.
- The use of distributed energy resources such as photovoltaic, wind generation, advanced batteries and fuel cells will be simplified.
- It will be easier and more profitable for commercial users to install their own generation (including highly efficient combined heat and power installations) and storage facilities.
- Large environmentally-friendly central plants such as wind and solar farms and advanced nuclear plants will be readily integrated into the transmission system.
- US dependence on fossil fuels will be reduced.

Design features and functions

- **Advanced real-time pricing technologies** – Price signals established to motivate consumer investment in distributed energy resources.
- **Smart meters and information gateways** – Consumer actions to be based on the real-time receipt and processing of price signals and other energy related information.
- **Smart sensors and control devices** – Intelligent electronic devices that provide the needed information and control capabilities necessary to integrate distributed energy resources with grid operations.
- **Standardized and widespread communications** – Enabling the coordination and control of many kinds of energy sources in many different places.
- **Advanced system planning tools** – Integrating the benefits of distributed energy resources and optimizing the siting of new, conventional, centralized power stations.

Expected benefits

Diverse resources with simple "plug and play" connections will dramatically multiply the options for electrical generation and storage.

Whatever type of generation or storage resource is needed, it will be easily connected as a modular component to meet the demand. The benefits of this kind of easily distributed resource include:

- Improved reliability at customer and system levels.
- Increased capacity.
- Reduced system costs.
- Reduced system peak demand and price spikes during peak periods.
- Reduced transmission line congestion.
- Reduced system restoration time following major events.
- Increased tolerance to security threats and attacks.
- Reduced need for new, centralized power stations and transmission lines.
- Improved power quality.
- Increased environmental benefits.

ENABLES MARKETS

This characteristic is particularly important because open-access markets expose and shed inefficiencies. The modern grid will enable more market participation through increased generation paths, more efficient aggregated demand response initiatives and the placement of energy storage and resources within a more reliable distribution system.

- Independent system variables, such as energy, capacity, location, time, rate of change of capacity, and resiliency may be most efficiently managed through the supply and demand of markets.
- Consumer response to price increases will mitigate demand. It will drive lower-cost solutions and spur new technology development.
- The challenge for the modern grid is to free regulators, owners, operators, and consumers to modify the rules of business to suit market conditions.
- By reducing congestion, the modern grid expands markets; it brings together more buyers and sellers
- New, clean energy related products will be offered as market options.

Seven Principal Characteristics of the Modern Grid
Self-heals
Motivates and Includes the consumer
Resists attack
Provides power quality for 21st century needs
Accommodates all generation and storage options
Enables markets
Optimizes assets and operates efficiently

Design features and functions

- **Planning** – Activities that forecast load and congestion, develop capacity and adequacy, and schedule outages.
- **Day ahead** – Short-term capacity requirements, megawatt injections and withdrawals, financial transmission rights, and ancillary services via bids and offers.
- **Real time** – Real-time generation dispatch, management of megawatt injections and withdrawals, security constrained economic dispatch, congestion management, and ancillary services.

- **Post-real time** – Settlement of energy dispatch and financial transactions and the analysis and auditing of day-ahead and real-time market operations.
- **Market infrastructure and support systems** – Systems, processes and functions that produce a high-quality power delivery infrastructure, including the systems that support market operations.

Expected benefits

The modern grid's open-access markets will help drive billions of dollars of waste out of the system. Examples include:

- The DOE National Transmission Grid Study, published in May 2002, states that the benefits of the existing wholesale electricity markets in the United States are $13 billion annually.
- Transmission Load Reliefs are the actions by operators to curtail proposed transactions in order to ensure reliability, according to procedures developed by the North American Electric Reliability Council. TLR actions have increased dramatically since the time they were first adopted in 1997. With the modern grid, these actions will be expected to dramatically decline.
- The Gridwise Alliance has estimated savings of $57 billion per year in capital and operating costs through 2025 with the implementation of electricity markets. [S*ource:* Estimating the benefits of the GridWise initiative: Phase I report. Rand Corporation technical report, document no. TR-160-PNNL, May 2004]

Seven Principal Characteristics of the Modern Grid
Self-heals
Motivates and Includes the consumer
Resists attack
Provides power quality for 21st century needs
Accommodates all generation and storage options
Enables markets
Optimizes assets and operates efficiently

OPTIMIZES ASSETS AND OPERATES EFFICIENTLY

The modern grid's assets and its maintenance will be managed in concert with one goal: to deliver desired functionality at minimum cost.

- This principal characteristic does not imply that assets will operate at or near capacity limits. Rather, assets will be managed to deliver only what is needed and only when it is needed.
- The grid will integrate near real-time data with advanced operating algorithms to improve decision-making and optimize both the capacity and the quality of electrical services.
- With near real-time data, condition-based maintenance will dramatically improve equipment failure rates and reduce their maintenance costs.

Design features and functions

- **Component wear models** – Software applications that predict wear accumulation, providing increasingly reliable determinants as their forecasts are validated against field results.
- **Equipment operation** – Sensors and other intelligent electronic devices collect data to ensure equipment operation meets design specifications.
- **Trending** – Algorithms that extract performance and maintenance trends from systems and equipment.
- **Utilization** –New operations and maintenance methods identify transformers in danger of overloading, balance circuit phases, reduce electrical losses and eliminate congestion in transmission lines.
- **Notifications** – Automated problem alerts are sent to human or automated asset managers for appropriate responses.

Expected benefits

Measurable benefits accrue when optimizing use and maintenance of system-wide assets with needed services.

- A general decrease in operation and maintenance costs along with the environmental benefits associated with improved electrical efficiency and fewer potentially polluting equipment failures.
- Cost savings from productivity improvements, the elimination of routine tasks, reductions in material use, and less reliance on outside contractors.
- Increased reliability due to longer equipment service times and fewer routine inspections and diagnostic tests.
- Reduced opportunities for human error by eliminating unnecessary maintenance.
- A change in focus from data gathering to thought gathering, including anticipatory decision-making.

Benefits of the Principal Characteristics

Principal Characteristic	Benefits
Self-heals	Enhances cost savings, reliability and the profitable marketing of surplus power.
Motivates & includes the consumer	Consumers use more wisely, helping utilities produce more efficiently resulting in a wide range of environmental benefits.
Resists attack	The grid deters or withstands physical or cyber attack.
Provides power quality for 21st century needs	Avoids productivity losses of downtime, especially in digital device environments
Accommodates all generation and storage options	Diverse resources with "plug-and-play" connections multiply the options for electrical generation and storage including new opportunities for more efficient, cleaner power production.
Enables markets	The grid's open-access market reveals waste and inefficiency and helps drive them out of the system while offering new consumer choices such as green power products.
Optimizes assets and operates efficiently	Desired functionality at minimum cost guides operations and the use of assets.

Achieving a modern grid with all necessary principal characteristics will require the application of well-chosen technologies. This is the subject of the next section, Key Technology Areas, the fourth primary element in our systems view.

APPLYING THE KEY TECHNOLOGY AREAS

The previous section's seven principal characteristics addressed the desirable features of the modern grid. This section describes the fourth primary element of our systems view — the key technology areas needed to attain those principal characteristics.

The Modern Grid Initiative has identified five key technology areas emerging to achieve the principal characteristics. These technologies have been proven in other industries and are essential to realizing the modern grid vision:

- **Integrated Communications** – High-speed, fully integrated, two-way communication technologies will make the modern grid a dynamic, interactive "mega-infrastructure" for real-time information and power exchange. Open architecture will create a plug-and-play environment that securely networks grid components to talk, listen and interact.
- **Sensing and Measurement** – These technologies will enhance power system measurements and enable the transformation of data into information. They evaluate the health of equipment and the integrity of the grid and support advanced protective relaying; they eliminate meter estimations and prevent energy theft. They enable consumer choice and demand response, and help relieve congestion.
- **Advanced Components** – Advanced components play an active role in determining the grid's behavior. The next generation of these power system devices will apply the latest research in materials, superconductivity, energy storage, power electronics, and microelectronics. This will produce higher power densities, greater reliability and power quality, enhanced electrical efficiency producing major environmental gains and improved real-time diagnostics.
- **Advanced Control Methods** – New methods will be applied to monitor essential components, enabling rapid diagnosis and timely, appropriate response to any event. They will also support market pricing and enhance asset management and efficient operations.
- **Improved Interfaces and Decision Support**– In many situations, the time available for operators to make decisions has shortened to seconds. Thus, the modern grid will require wide, seamless, real-time use of applications and tools that enable grid operators and managers to make decisions quickly. Decision support with improved interfaces will amplify human decision making at all levels of the grid.

The integrated suites of technologies needed to support the achievement of the principal characteristics will emerge from one or more of these key technology areas. Whether building a modern grid for a region, city, or community, the process of determining which suite of technologies serve the principal characteristics will also drive the best integrated fit.

DEVELOPING METRICS TO MEASURE PROGRESS

The beginning of this document confronts the tough systems view questions about success factors, performance, principal characteristics and technologies. Answers to each of these questions have been framed in four of the primary elements of our systems view.

This section discusses the fifth and last element of the systems view as it confronts the important question: How do we know if we're succeeding, and if not, what mid-course corrections are needed?

Collaboratively developed metrics enable consumers, utilities, and other industry participants to evaluate the effectiveness of the modern grid.

MGI-sponsored discussions with industry experts resulted in an initial set of metrics that were deemed important:

- Customer Average Interruption Duration Index (CAIDI)
- Cost of Interruptions and power quality disturbances
- Ratio of distributed generation to total generation
- Ratio of renewable generation to total generation
- Peak and average energy prices by region
- Peak-to-average load ratio
- Transmission congestion costs
- Duration congested transmission lines are loaded >90%
- System electrical losses
- Consumers participating in energy markets
- Total cost of delivered energy
- Emissions per kilowatt-hour delivered

Metrics for the modern grid continue to evolve and become more specific. The primary approach is to rely heavily on stakeholder input collected through working group interactions. This will allow stakeholders to define grid metrics that relate to national performance issues, as well as performance at regional and local levels.

The accountability that comes from trending metrics is a vital driving force for improving performance and getting to the bottom of issues as they appear.

SUMMARY

This systems view of the modern grid identifies a structured approach to making changes urgently needed in the nation's power delivery system. It directs our planning to the most important things to do and organizes that planning into five primary elements:

1. **Key Success Factors** – What the goals of the grid should be.
2. **Performance** – What the grid must do to meet those goals.
3. **Principal Characteristics** – What important features it must possess to meet performance requirements.
4. **Key Technology Areas** – Which technologies support the desired characteristics.
5. **Metrics** – How we gauge progress.

The key success factors establish a basis for specific performance requirements and keep us mindful of the strategic reasons for developing a modern grid. Goals such as greater reliability, impervious security, and environmental quality guide the major decisions about how the modern grid is to be developed.

Performance requirements describe the essential tasks that the modern grid must do better to meet its key success factors. From routine operations to emergency response, the modern grid will have to predict problems before they occur, avert disruptions whenever possible and restore lost service before it becomes damaging.

Principal characteristics comprise the seven main features that a modern grid needs to meet its essential performance requirements. Included among these are the characteristics that enable the grid to self-heal after any disruption, resist attack, provide cleaner power to digital devices, protect the environment and constantly optimize its own performance to achieve order-of-magnitude improvements.

Key technology areas are those particular technologies that support the modern grid's principal characteristics. Seamless networking of communications, sensors, and meters using advanced digital components and computer-aided controls attain the grid's desired characteristics and with dramatic improvement in efficiencies and environmental benefits.

Metrics will be the yardstick for objectively gauging how well the modern grid is fulfilling its promises. The durations of interruptions, costs of congestion, environmental impact and energy prices are just a few of the ways that consumers, utilities, and investors will follow the grid's development and performance.

By keeping the systems view in mind, all stakeholders committed to improvements have a compass that will help stay the course to a truly viable modern grid solution.

CALL TO ACTION

Creating the modern grid will require a monumental effort by all stakeholders. With a clear vision, we can generate the alignment needed to inspire passion, investment, and movement toward that vision. Your input is needed, along with your acceptance, which will ultimately lead to stakeholder alignment.

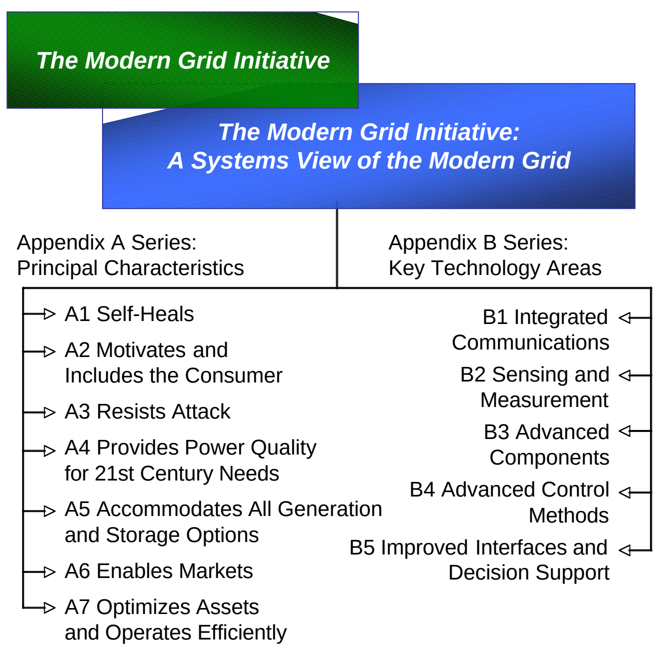
Visit our website at www.netl.doe.gov/moderngrid/ to find out how you can become more involved in this national effort to modernize the grid. The website is a resource with contact details for speaking directly with a team member, and it summarizes the benefits of participating in a working group.

We want your thoughts. Take action in support of the Modern Grid Initiative by providing feedback. You can do this by:

- Participating in Modern Grid Initiative regional summit meetings, where you can personally provide your input.
- Interacting with team members through the Modern Grid Initiative website, where you can discuss and resolve questions and issues.
- Participating as a working group member, where you can take an active role in the implementation of the Modern Grid Initiative.

This high-level overview is one of a collection of documents prepared by The Modern Grid Initiative. For additional background on the motivating factors for the modern grid, see the whitepaper "The Modern Grid Initiative."

MGI has also prepared seven papers that support and supplement these overviews by detailing more specifics on each of the principal characteristics of the modern grid. In addition five other papers have been prepared to further discuss the Key Technology Areas.



APPENDIX A SERIES: PRINCIPAL CHARACTERISTICS

A1 Self-Heals
A2 Motivates and Includes the Consumer
A3 Resists Attack
A4 Provides Power Quality for 21st-Century Needs
A5 Accommodates all Generation and Storage Options
A6 Enables Markets
A7 Optimizes Assets and Operates Efficiently

APPENDIX B SERIES: KEY TECHNOLOGY AREAS

B1 Integrated Communications
B2 Sensing and Measurement
B3 Advanced Components
B4 Advanced Control Methods
B5 Improved Interfaces and Decision Support