Appendix B1:
A Systems View of the Modern Grid

INTEGRATED COMMUNICATIONS

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

NETL

Office of Electricity Delivery and Energy Reliability

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The United States urgently needs a fully modern power grid if we are to meet our country's requirements for power that is reliable, secure, efficient, economic, and environmentally responsible.

To achieve the modern grid, a wide range of technologies must be put into operation. These technologies can be grouped into five key technology areas, as seen in Figure 1:

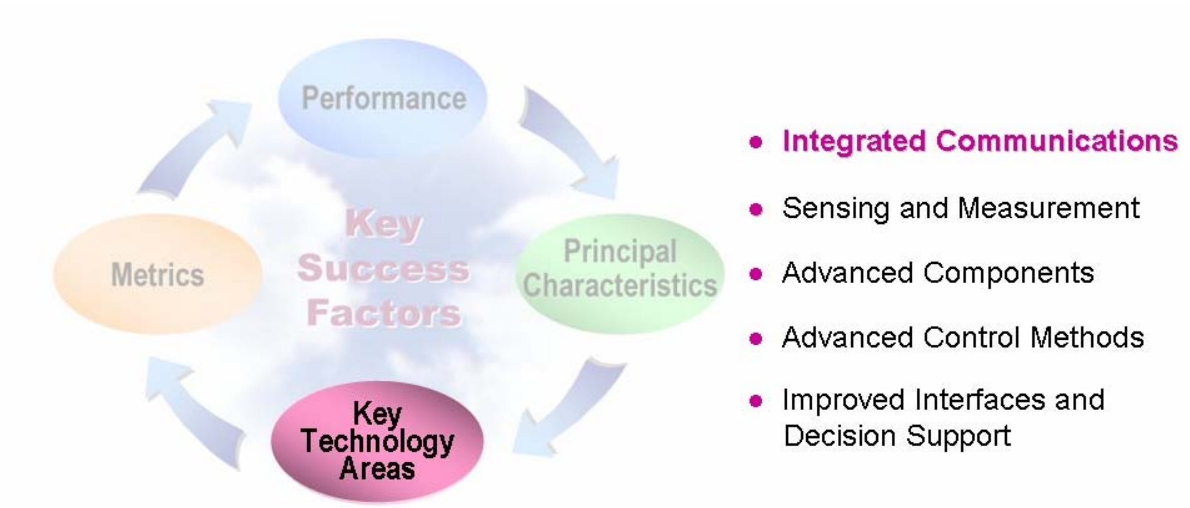


Figure 1: The Modern Grid Systems View provides an "ecosystem" perspective that considers all aspects and all stakeholders.

Of these five key technology areas, the implementation of integrated communications is a foundational need, required by the other key technologies and essential to the modern power grid. Due to its dependency on data acquisition, protection, and control, the modern grid cannot exist without an effective integrated communications infrastructure. Establishing these communications must be of highest priority since it is the first step in building the modern grid.

Integrated communications will create a dynamic, interactive "mega infrastructure" for real-time information and power exchange, allowing users to interact with various intelligent electronic devices in an integrated system sensitive to the various speed requirements (including near real-time) of the interconnected applications.

As a first order of business, there is a need to specify the technical requirements for the system (e.g., speed, redundancy, reliability). Various utility applications have different demands, and these must be fully defined up front.

Second, standards development must be seriously addressed and encouraged. Although communications media technologies are being developed very rapidly, their widespread deployment will be seriously delayed unless the development of universal standards is accelerated.

This paper covers the following four important topics:

- Current state of integrated communications
- Future state of integrated communications
- Benefits of implementation
- Barriers to deployment

Although it can be read on its own, this paper supports and supplements "A Systems View of the Modern Grid," an overview prepared by the Modern Grid Initiative team.

CURRENT STATE

Before we see what the modern grid will look like with integrated communications in place, we will first consider the present state of communications in our nation's power grid.

The communications systems utilized in the power industry today are too slow and too localized to support the integrated communications needed to enable the modern power grid. An open communications architecture that supports "plug and play" interoperability is needed. Further, universally accepted standards for these communications must be defined and agreed upon in the industry.

COMMUNICATIONS STANDARDS

For communications in the grid to be truly effective, they must exist in a fully integrated system. And to be fully integrated, universal standards must be applied. Although numerous communication standards already exist today, the establishment and adoption of *universal* standards by users, vendors, and operators is lacking but greatly needed. Until these universal standards are set for the various functionalities required by the modern grid, investors will be reluctant to invest, and lack of funding will severely limit attainment of a modern grid.

One exception is in the area of substation automation (SA). The International Electrotechnical Commission (IEC), a recognized authoritative worldwide body responsible for developing consensus in global standards in the electro-technical field, has developed IEC 61850 for SA. This appears to have become the universally adopted standard for SA. Additional IEC standards for advanced meter reading (AMR), demand response (DR), and other modern grid features are expected to be adopted in the future.

However, at present universally adopted standards do not yet exist for most user-side features such as AMR and DR. In his *A Strawman Reference Design for Demand Response Information Exchange* (Draft), Erich Gunther of EnerNex Corporation recommends the formation of "an industry-driven working group to work out the details of the reference design and set up the mechanisms for already existing standards bodies to contribute."

The question of setting standards is expected to be addressed by the Open AMI Technical Subcommittee. Open AMI is a task force working under the UCA International Users Group, a non-profit organization whose members are utilities, vendors, and users of communications for utility automation. One of Open AMI's specific objectives is to "define what open standards means for advanced metering and demand response."

In another example of the search for common standards, the Institute of Electrical and Electronics Engineers (IEEE) is currently working on standards for Broadband over Power Line (BPL) technologies. However, user standards, such as advance metering and DR, have not yet been developed. Standards development, testing, and adoption could take five to ten years to complete.

Communications Media and Technologies

A variety of communications media are used in today's electric grid, including copper wiring, optical fiber, power line carrier technologies, and wireless technologies. Using these media, many U.S. facilities have deployed SA, an excellent first step in integrating grid communications. However, SA does not yet fully integrate with the other features that will modernize our power grid.

Limited deployment of distribution automation (DA) has also occurred. Low speed transmission supervisory control and data acquisition (SCADA) and energy management system (EMS) applications have been successfully integrated among regional transmission organizations, generators, and transmission providers. But these applications still lack full utilization of the integrated, high-speed communications system required by the modern grid.

Power line carrier technology has been in use for many years in the utility industry. Recently, BPL carrier technologies have been developed and successfully demonstrated on a pilot basis. Also, wireless technologies are currently being developed and demonstrated, but they are not yet used in the grid communications infrastructure on either the system or the user side.

The current state of communications technologies described in the three tables below are in various stages of availability, deployment, or development.

Broadband over Power Line

Originally focused on Internet access and voice over Internet protocol for consumers, BPL is increasingly being deployed to meet utility needs for distributed energy resources (DER), AMR, DR, and consumer portal applications, as well as DA and video monitoring (primarily for security) applications and other high-speed data needs on the system side.

Broadband over Power Line	
Name	**Description**
Broadband over power line	• Meets some utility needs for AMR, DER, DR, and consumer portal applications, as well as DA, video monitoring, and other high-speed data applications • Deployable only over low- and medium-voltage distribution facilities • Demonstrated in over 30 pilots and trials • Has not penetrated the communications market as the lead candidate for supporting the modern grid's communications infrastructure • Deployment and integration with distribution facilities currently limited • Numerous vendors are aggressively marketing these products • Next-generation systems now under development promise lower cost, improved performance, higher speed, and utility applicability • Application at transmission voltages may also be viable • Radio frequency interference with ham radio identified in some BPL technologies; however, techniques have been developed and appear effective in eliminating the interference

Table 1: Broadband over power line (BPL) technology

Wireless Technologies

Various wireless technologies are emerging as possible candidates for the communications infrastructure of the modern grid. To date, few of them have made significant market penetration in either system- or user-side applications.

Table 2: Wireless Technologies

Wireless Technologies	
Technology	**Description**
Multiple address system radio	• Consists of a master radio transmitter/receiver and multiple remote transmitters/receivers • Master can access multiple units • Can be used as a repeater radio to transmit signals over or around obstructions • Used widely by utilities for SCADA systems and DA systems • Flexible, reliable, and compact

Wireless Technologies	
Technology	**Description**
Paging networks	• Radio systems that deliver short messages to small remote mobile terminals • One-way messaging is cost effective, but two-way is generally cost prohibitive • Some paging standards exist, but many systems remain proprietary
Spread spectrum radio systems	• Used in point-to-multipoint radio systems • Can operate unlicensed in 902-928 MHz band but must continually hop over a range of frequencies • Line of sight is needed for optimal coverage • Often used as last-mile connection to a main communications system
WiFi	• Utilizes IEEE 802.11b and IEEE 802.11g • Data transfer rates range from 5 – 10 Mbps for 802.11b and up to 54 Mbps for 802.11g • Effective for in-office or in-home use • Range is only about 100 meters
WiMax	• Utilizes IEEE 802.16 • Provides longer distance communications (10 – 30 miles) with data transfer rates of 75 Mbps • May be used as the spine of a transmission and distribution communications system that will support WiFi applications for SA or DA • Can communicate out-of-sight using IEEE 802.16e and can communicate with moving vehicles • Communicates point-to-point with different vendors
Next-generation cellular (3G)	• Can be applied as a low-cost solution for SA to control and monitor substation performance when small bursts of information are needed • May not meet the quality needs of online substation control and monitoring • Expected to be cost effective and quickly implemented • Coverage may not be 100% (some dead zones)
Time division multiple access (TDMA) Wireless	• Digital cellular communication technology that allocates unique time slots to each user in each channel • Utilizes IS-136 standard • Two major (competing) systems split the cellular market: TDMA and CDMA (see below); third-generation wireless networks will use CDMA

Wireless Technologies	
Technology	**Description**
Code division multiple access (CDMA) wireless	• Has become the technology of choice for the future generation of wireless systems because network capacity does not directly limit the number of active radios; this is a significant economic advantage over TDMA • Has been widely deployed in the United States • Utilizes the IS-95 standard which is being supplanted by IS-2000 for 3G cellular systems
Very small aperture terminal (VSAT) satellite	• Provides new solutions for remote monitoring and control of transmission and distribution substations • Can provide extensive coverage • Can be tailored to support substation monitoring and provide GPS-based location and synchronization of time (important for successful use of phasor measurement units) • Quickly implemented • High cost, except for remote locations • Functionality effected by severe weather

Table 2: Wireless technologies

Other Technologies

The table below includes other communication technologies that support, or could support, the modern grid.

Table 3: Other Technologies

Other Technologies	
Technology	**Description**
Internet2	• Next-generation high-speed internet backbone • More than 200 universities are working to develop and deploy advanced network applications
Power-line carrier	• Supports advanced metering infrastructure (AMI) deployments and grid control functions, such as load shedding • Communicates over electric power lines • Provides low-cost, reliable, low- to medium-speed, two-way communications between utility and consumer

Other Technologies	
Technology	**Description**
Fiber to the home (FTTH)	• Provides a broadband fiber-optic connection to customer sites • Costs of installation and associated electronics prohibitive • For decades, has been the "holy Grail" of the telecommunications industry, promising nearly unlimited bandwidth to the home user • To be cost-effective, needs passive optical network, which permits a single fiber to be split up to 128 times without active electronic repeaters; general decrease in cost of electronics is also helpful
Hybrid fiber coax (HFC) architecture	• Uses fiber to carry voice, video, and data from the central office (head end) to the optical node serving a neighborhood • Cable operators have begun plant upgrades using HFC to provide bi-directional services, such as video-on-demand, high-speed Internet, and voice-over-Internet protocol
Radio frequency identification (RFID)	• Uses radio frequency communication to identify objects • Provides an alternative to bar codes • Does not require direct contact or line-of-sight scanning • Low-frequency systems have short ranges (generally less than six feet); high-frequency systems have ranges of more than 90 feet

Table 3: Other technologies

No limitations are expected in the development of any of the media commonly used today (copper, fiber, power-line carrier, and wireless technologies). Radio frequency interference has been identified in some BPL technologies, but this issue is not expected to have a major impact on the future development and deployment of BPL.

The Common Information Model (CIM) is the industry standard for monitoring and controlling enterprise computing environments. Lessons learned from applying CIM to solve past data exchange issues will be applied to the integrated communications infrastructure of the modern grid. Through CIM techniques, the seamless interchange of all data with all applications and users can be achieved.

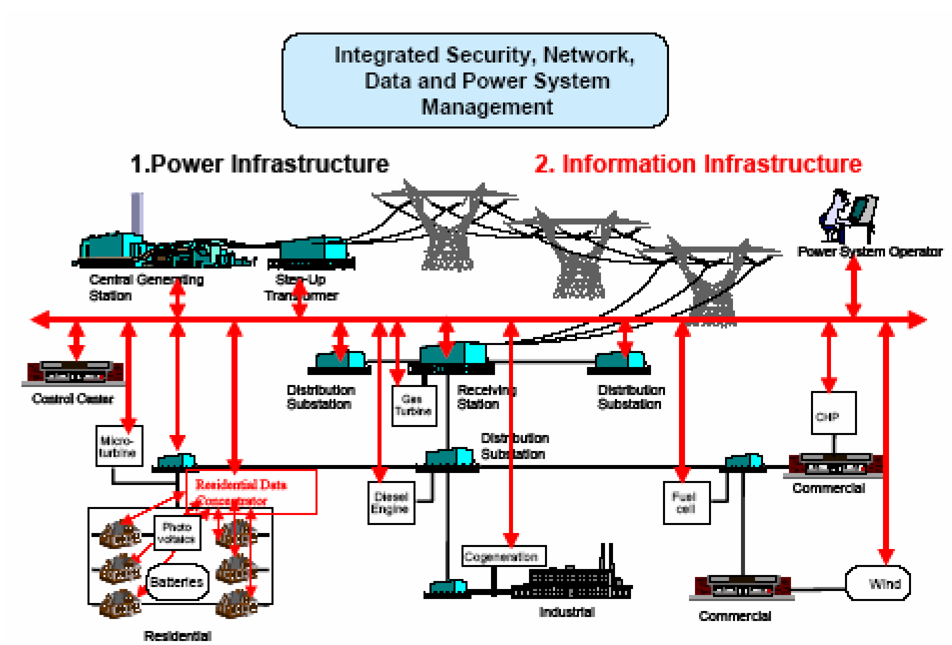
FUTURE STATE

An effective, fully integrated communications infrastructure is an essential component of the modern grid

Integrated communications will enable the grid to become a dynamic, interactive medium for real-time information and power exchange. When integrated communications are fully deployed, they will optimize system reliability and asset utilization, enable energy markets, increase the resistance of the grid to attack, and generally improve the value proposition for electricity.

Through advanced information technology, the grid system will be self-healing in the sense that it is constantly self-monitoring and self-correcting to keep high quality, reliable power flowing. It will also sense disturbances and instantaneously counteract them or reconfigure the flow of power to mitigate damage before it can propagate. The integrated communications infrastructure is necessary to enable the various intelligent electronic devices (IEDs), smart meters, control centers, power electronic controllers, protection systems, and users to communicate as a network.

Figure 2 gives one view of the complexity of the integrated communications systems required to support the modern grid.



Source: EPRI

Figure 2: Communication environments: Integration of enterprise and power System management. Image courtesy of EPRI.

These integrated systems will provide two fundamental functions that will effectively support modern grid operations:

- **Open communications standards** that have the necessary intelligence to enable information to be recognized and understood by a wide assortment of senders and receivers
- **Appropriate media** that will provide the necessary infrastructure to transmit information accurately, securely, reliably, and at the required speed with the required data throughput

Most importantly, it is these two functions that will instill confidence in investors and motivate them to invest in the other key technology areas required by the modern grid.

High-speed, fully integrated, two-way communications technologies will allow much-needed real-time information and power exchange. Open architecture will create a plug-and-play environment that networks the grid components together for talk and interaction.

Universal standards will provide for all sensors, IEDs, and applications to communicate seamlessly at the speed necessary to support all required functions. These standards, when adopted by all parties, will provide confidence to stakeholders that their investments in integrated communications for the grid will not be stranded.

The integrated communications infrastructure of the modern grid will possess the following characteristics:

- **Universality** – All potential users can be active participants.
- **Integrity** – The infrastructure operates at such a high level of manageability and reliability that it is noticed only if it ceases to function effectively.
- **Ease of use** – Logical, consistent, and intuitive rules and procedures are in place for the user.
- **Cost effectiveness** – The value provided is worth the cost.
- **Standards** – The basic elements of the infrastructure and the ways in which they interrelate are clearly defined and remain stable over time.
- **Openness** – The public part of the infrastructure is available to all people on a nondiscriminatory basis.
- **Security** – The infrastructure is able to withstand security attack, and users have no fear of interference from others.
- **Applicability** – The infrastructure will have sufficient bandwidth to support not only current functions but also those that will be developed in the future.

Benefits of Implementation

One of the main benefits to be gained from implementation of integrated communications will be the grid's ability to self-heal.

The near real-time acquisition and transfer of data will support the grid's ability to detect, analyze, and respond autonomously to adverse trends and conditions. Further, integrated communications will enable the development of new, real-time analytical tools, including wide area measurement technologies that will assist system operators in predicting and preventing events that negatively affect grid reliability and will also aid in the post-mortem analysis of such events.

Another benefit is that the grid will become more reliable when integrated communications are in place because they will make possible a broader application of alternative resources, including renewables that depend on an integrated communications system to become an effective part the grid system. A more effective and reliable dispatch of centralized generation, flow and VAr control, DER, and DR resources will be available to system operators by the near real-time data provided by integrated communications.

The grid will be more secure from outside threats when integrated communications have been implemented. All will benefit when the availability of near real-time data over a secure communications infrastructure provides detection and mitigation of both cyber and physical threats to the grid (See “Appendix A3: Resists Attack”). As an additional bonus, the integrated communications system will facilitate security monitoring of even non-grid infrastructures because the electric grid physically reaches virtually all other sensitive societal systems.

Another way in which Integrated communications will make the grid more secure is by providing the key data needed by emergency response organizations in a timely manner, which will reduce restoration times following major grid events.

As a further benefit, the environmental impact of producing power will be significantly reduced by the modern grid's integrated communications technologies. Providing the needed data will enable DER to be dispatched as a system resource, leading to an increased investment in DER (single units as well as larger DER “farms”), particularly those units that are environmentally friendly, such as wind, solar, and geothermal. The wide use of renewable DER and DR depends on the ability of the grid to address their intermittency and effectively integrate them with grid operations.

Significant economic benefits will follow implementation of integrated communications and the other key technologies of the modern grid.

The following list shows some of the economic benefits that will be enabled by integrated communications:

- The overall reliability of distribution and transmission systems will improve, leading to decreased costs and increased revenues.
- The grid will operate more economically for all stakeholders by making available the collection and transfer of market information, prices, and conditions to participants.
- The high-speed data needed for identifying and correcting power quality issues will be provided, leading to a reduction in quality-related costs currently incurred by consumers and grid operators. At the same time, equipment condition data needed by asset management processes will be provided, leading to a reduction in failure-related maintenance and outage costs.
- The need for new and costly hard assets will lessen as integrated communications technologies provide an alternative way to increase grid reliability rather than adding new and costly hard assets.
- Consumers will profit as well when the integrated communications infrastructure enables them to make financially smart energy choices. Providing price signals to consumers will motivate them to participate in the electricity market based on real supply and demand influences. Also, the integrated communications will link end users with communications options for non-utility applications, such as home security.
- Major long-term investments needed to increase system capacity will become more cost effective when asset-utilization data is integrated into the distribution and transmission planning models.
- The data and information made available to the modern grid using integrated communications technologies will also greatly benefit other enterprise-wide processes and technologies, such as asset management, work management, outage management, and also GIS-based systems.

BARRIERS TO DEPLOYMENT

Lack of an industry vision for integrated communications and a lack of understanding for the benefits of this technology are the greatest barriers to their deployment.

Research and development efforts are yielding communications media technologies that will support the needs of the modern grid. However, successful deployment of these technologies has not yet been achieved. Some of the gaps that must be overcome are described below:

- **There are no universal communications standards** that promote interoperability and enable the various communication technologies to work as an integrated suite.
- **So far, stakeholders have not developed and endorsed** a clearly defined communication architecture that will meet the requirements of the modern grid, or the transition plan needed to achieve such architecture. The transition plan needs to illustrate how to reach the desired future state without significant loss due to stranded investments.
- **Regional and national demonstrations of communications technologies are needed** to create interest, excitement, and the societal, political, and economic stimuli that will accelerate their deployment. It is likely, however, that different solutions will be required to address differing regional landscapes.
- **Regulatory and policy-setting bodies have not yet provided the regulations that will ensure that investments in new technologies will not lead to losses.** Deployment of modern grid technologies is costly, and without such incentives, utilities and energy providers are reluctant to invest in the needed technology areas even though these efficiency improvements will benefit the consumer and will provide great societal benefits, such as a cleaner, safer environment. Creative regulatory solutions are needed to assure that utilities and energy providers are protected financially (i.e., remain "revenue neutral.")
- **We do not yet have effective consumer education to create interest and motivation among the consumer groups**. Consumers can realize substantial benefits when the modern grid vision is achieved. Currently these benefits are not clear to the consumer. In order for consumers to value investment in communications systems, they must have a stronger link to grid operators and energy providers.
- **Vendors who supply sensors, IEDs, DER, and other end-use devices are hesitating to invest in these products until universal standards are adopted.** To compensate for the lack of universal standards, some vendors are creating their own proprietary solutions and protocols to enable them to bring specific products to market. This approach has the potential to create stranded investments and rework in the future as universal standards are ultimately adopted. There is also the danger that these vendor-specific protocols will

become industry standards by default rather than standards set through conscious and intelligent evaluation of what is most advantageous for all stakeholders.

POSSIBLE SOLUTIONS

The answer to overcoming these barriers to deployment lies in gaining buy-in from all stakeholders of the modern grid. Regulation and legislation, such as the Energy Policy Act of 2005, may serve as a catalyst for technology deployment, but more is needed.

Only by motivating all stakeholders to invest in the modern grid vision will widespread deployment of integrated communications be hastened. Here are three steps toward that goal:

- **Energy consumers must be informed about the cost of energy and the benefits of an integrated communication system**. An understanding of real-time pricing will motivate them to demand an integrated communications system that will support their ability to manage energy consumption.

  The technologies needed to motivate the consumer to invest include a cost-effective communications system that enables consumer-portal functionality and possibly broadband Internet service.

- **Energy companies need to clearly see the improved reliability, reduced cost, and increased revenues that integrated communications and the modern grid will bring.** This understanding will motivate them to work more quickly toward the universal standards needed to allay the natural fear of having large investments stranded due to changes in technology over time.

  Cost-effective and universally accepted standard communication technologies need broad acceptance. These will motivate energy companies to invest in applications that can satisfy their interests. Regional and national demonstrations of these technologies would bring the needed exposure to energy company executives.

- **Vendors will be motivated to invest in new products when they see a market for them**. As consumers and energy companies catch the vision, they will demand from vendors the next generation of products needed to support the modern grid.

In addition to increasing stakeholder demands for a communications infrastructure, a specific schedule of requirements needs to be established through regulation or legislation to accelerate completion of the universal standards and the deployment and marketing of associated communications technologies.

SUMMARY

Achievement of the modern grid vision is fully dependent on integrated communications technologies.

Implementation of these technologies, the first step toward achieving a truly modern power grid, will lead to major gains in reliability, security, economy, safety, efficiency, and improved environmental performance.

In general terms, an effective integrated communications system will provide the information and data necessary to optimize the reliability, asset management, maintenance, and operations required by a modern power grid.

The acceptance of universal standards will encourage the continued development and effective deployment of the needed communication infrastructure and other technologies. In addition, it is likely that demand will drive prices down.

Without a modern communications infrastructure, however, the modern grid cannot become a reality. Our nation's power grid must be updated through implementation of five key technology areas: Integrated Communications, Sensing and Measurement, Advanced Components, Advanced Control Methods, and Improved Interfaces and Decision Support. Of these five, integrated communications is of first importance since this technology enables the other four.

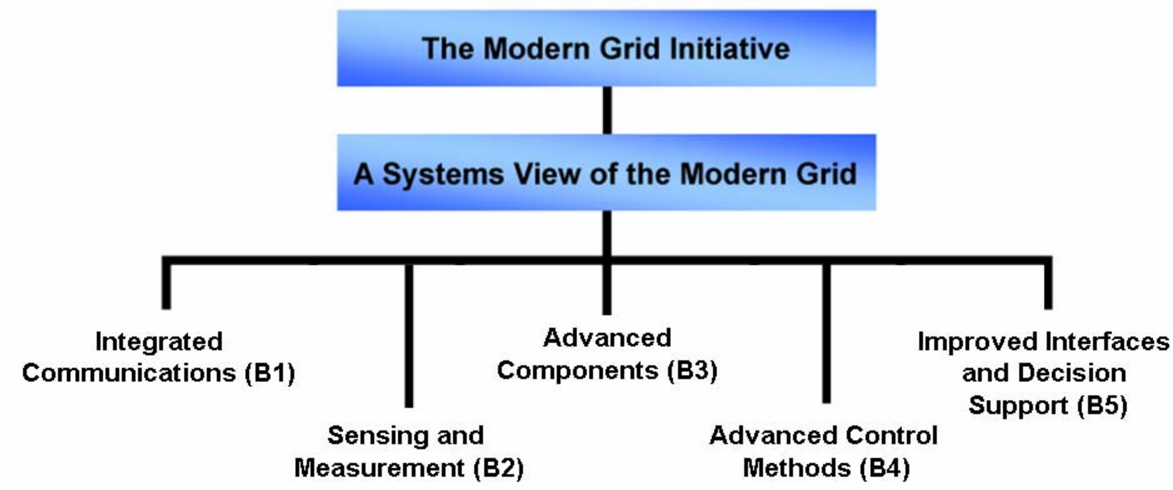
The electric utility industry has lagged behind other industries in taking advantage of the enormous strides in communication technology that have been made in the past decades. While the technologies needed to establish a modern grid are within reach, the industry has yet to focus on this opportunity.

Until these barriers are overcome, our power grid remains vulnerable to costly large-area blackouts such as was experienced in the Great Lakes region in 2003. Action is needed on the part of all stakeholders for integrated communications to be fully deployed and the multiple societal benefits of a modern grid to be realized. Integrated communications will open the way for the other key technology areas to be accepted and implemented, leading to the full modernization of our power grid.

For more information

This document is part of a collection of documents prepared by the Modern Grid Initiative (MGI) team. For a high-level overview of the modern grid, see "A Systems View of the Modern Grid." For additional background on the motivating factors for the modern grid, see "The Modern Grid Initiative."

MGI has also prepared five papers that support and supplement these overviews by detailing more specifics on each of the key technology areas of the modern grid. This paper has described the first key technology area, “Integrated Communications.”



These documents are available for free download from the Modern Grid Web site.

The Modern Grid Initiative

Website: www.netl.doe.gov/moderngrid

Email: moderngrid@netl.doe.gov

(304) 599-4273 x101

BIBLIOGRAPHY

Electric Power Research Institute. 2004. Integrated energy and communications architecture: Volume IV: Technical analysis, appendix D, technologies, services, and best practices. Palo Alto, CA: EPRI.

Gunther, E. 2004. A strawman reference design for demand response information exchange. Report prepared for the California Energy Commission (draft).

Institute of Electronic and Electrical Engineers. 2003. IEEE-SA TR1550 Communication Requirements, Version 5.

Schmidt, R. and T. Lebakken. 2005. Broadband power line communications: Where is it? What to consider? Utility University course presented prior to Distributech Conference and Exhibition, San Francisco, CA.

Schwarz, K. 2004. IEC 61850 and UCA™ 2.0: A discussion of the history of origins.

Sumic, Z. and J. Spiers. 2004. The grid is becoming smarter: How about you? Stanford, CT: META Group.

Thorpe, J. 2004. Session V: Countermeasures. Synopsis presented at CRIS International Workshop on Power System Blackouts – Causes, Analyses, and Countermeasures, Lund, Sweden.

Yeager, K. E. and C. W. Gellings. 2004. A bold vision for T&D. Paper presented at the Carnegie Mellon University Conference on Electricity Transmission in Deregulated Markets, Pittsburgh, PA.

ACRONYMS LIST

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
BPL	Broadband over Power Line
DA	Distribution Automation
DER	Distributed Energy Resources
DR	Demand Response
EMS	Energy Management System
GIS	Geographic Information System
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
SCADA	Supervisory Control and Data Acquisition
VAr	Volt-amperes reactive