NETL Modern Grid Strategy
Powering our 21st-Century Economy

A Compendium of Smart Grid Technologies

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INTRODUCTION

A fully modernized grid is essential to provide service that is reliable, secure, cost-effective, efficient, safe, and environmentally responsible. To achieve this vision of the smart grid, a wide range of technologies must be developed and implemented. These technologies can be grouped into the following five Key Technology Areas (KTAs):

- **Integrated Communications**—High-speed, fully integrated, two-way communication technologies that make the smart grid a dynamic, interactive "mega-infrastructure" for real-time information and power exchange. An open architecture creates a plug-and-play environment that securely networks grid components, customers, and operators, enabling them to talk, listen, and interact.
- **Advanced Components**—Advanced components play an active role in determining the electrical behavior of the grid. These power system devices apply the latest research in materials, superconductivity, energy storage, power electronics, and microelectronics to produce higher power densities, greater reliability and power quality, enhanced electrical efficiency that produces major environmental gains, and improved real-time diagnostics.
- **Advanced Control Methods**—New methods and algorithms monitor power system components, enabling rapid diagnosis and timely, appropriate response to any event. They also support market pricing and enhance asset management and efficient operations.
- **Sensing and Measurement**—Technologies that enhance power system measurements and enable the transformation of data into information. They evaluate the health of equipment, the integrity of the grid, and support advanced protective relaying. They enable consumer choice and demand response, and help relieve congestion.
- **Improved Interfaces and Decision Support**—The smart grid will require wide, seamless, often real-time use of applications and tools that enable grid operators and managers to make decisions quickly. Decision support and improved interfaces will enable more accurate and timely human decision making at all levels of the grid, including the consumer level, while also enabling more advanced operator training.

This document provides a living compendium of technologies categorized by Key Technology Area—both individual ones as well as some that have been integrated. Some technologies are commercially available and others are still under development. Its content is based on website searches and networking conversations with industry, government, and academia experts. Users should consult the listed references to obtain the latest information.

INTEGRATED COMMUNICATIONS

Table 1: Integrated Communications

Integrated Communications			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References***
100 Gigabit Ethernet (GbE)	~2 years	A national-scale, prototype 100-gigabit per second data network linking research centers across the nation. This effort will enhance the Office of Science's networking capabilities and benefit the commercial telecommunications sector.	https://mail.internet2.edu/wws/arc/i2-news/2008-11/msg00000.html; http://www.energy.gov/news2009/7083.htm
Internet 2	~3 Years	Internet 2 development is led by more than 200 universities for next-generation high-speed Internet backbone. IPv6 extends an Internet IP address scheme to 6 octets, which is desirable for BPL-based ISP services. With high performance backbone and MPLS QoS services, integration of QoS sensitive applications is directly supported.	http://www.internet2.edu/; http://www.ipv6.org/
Broadband over Power Line (BPL) Low-Medium Voltage Lines	Available	BPL is a technology that allows digital data to be transmitted over utility power lines. BPL works by modulating high-frequency radio waves with the digital signals from the Internet. These radio waves are fed into the utility grid at specific points. They travel along the medium-voltage wires and pass through, or bypass the utility transformers to subscribers' homes and businesses. Little, if any, modification is necessary to the utility grid conductors to allow transmission of BPL signals. This mode has not yet been widely deployed in the United States, but it has been implemented in a few other countries, with varying results. Some engineers have expressed fear that BPL will interfere with fire, police, shortwave, land mobile, and other radio systems important to national security; amateur radio operators have voiced their concerns as well. In response the BPL industry has developed frequency notching techniques that have eliminated interference with such essential radio systems. Standards for BPL are now in development and will be needed for broader market acceptance. BPL is effective over short distances (up to one mile) without repeating and much longer distances (tens of miles) with repeating at 2–50 MHz and can achieve data transfers of 20–400 Mbps.	http://www.amperion.com/; http://www.currenttechnologies.com/; http://www.ambientcorp.com/; http://www.homeplug.org/; http://www.bpltoday.com/
BPL High Voltage Lines	3–5 years	A pilot project was performed with successful results over 5 miles of 69 kV lines. Higher-voltage-level systems are under development. High Voltage (HV) BPL may be used for transmission line protection, remote substation Supervisory Control and Data Acquisition (SCADA), Phasor Measurement Unit (PMU) data streaming, station surveillance, VOIP, and extension of utility fiber networks to remote stations. HVBPL could prove to be very attractive for the provision of high-speed data links between substations where no existing infrastructure is in place. It can certainly provide a complementary solution to the other technologies being used for smart grid deployments.	http://www.amperion.com/

* The website/internet references are accurate as of April 27, 2009; however, the content and address for websites are subject to change.

Integrated Communications			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References***
Hybrid Fiber Coax (HFC)	~2 Years	HFC architecture uses fiber to carry voice, video, and data from the headend or central office to an optical node serving a neighborhood. At the optical node, the downstream optical signal is converted to an electrical signal and carried via coax to terminal points at customer locations to provide broadband data service (televisions, computers, telephones, etc.). Services on these systems are carried out on radio frequency (RF) signals in the 5 MHz to 1000 MHz frequency band. A single optical node will typically support a number of coaxial distribution feeds. Due to the popularity of bi-directional services such as Video-on-Demand, high-speed Internet, and Voice-over IP, cable operators have installed plant upgrades that provide these services.	http://www.iec.org/online/tutorials/hfc_dwdm/; http://www.iec.org/online/tutorials/hfc_tele/yhyug
Power Line Communication (PLC)	Available now	Advanced Metering Infrastructure (AMI) deployment requirements have led to the development of proprietary PLC solutions, which also support grid control initiatives such as load shedding. The Two-Way Automatic Communication System (TWACS®) is a fixed network utility communication system that uses patented technologies to communicate over electric power lines or via short hop radio frequency (RF), providing low-cost, highly reliable, two-way communication between the utility and the consumers of electricity, gas, propane, and pit-set meters. The TWACS system uses the existing power lines for data transmission, and since it modulates the waveform at the zero crossing point, it uses the utility's network at the frequency for which it was designed. TWACS technology is a state-of-the-art, proven, reliable, multi-functional, power line and radio frequency communication system with full two-way access to and from the meter. This low-speed PLC system could provide connectivity to the customer, but first-time installation costs are significant.	http://www.aclaratech.com/AclaraPLS/pages/default.aspx
Narrowband PLC (IEC 61334-5) Device Language Message Specification (DLMS)	Developed and deployed in Europe; limited deployment in North America	Narrowband PLC is typically used for low-speed applications like Automatic Meter Reading (AMR) and Command & Control, thus most PLC devices support communication interface standards such as SPI, RS232, or RS485. Use of narrowband PLC for access between the utility and the customer site has been greater in Europe than in North America because of the higher number of customers connected to each low-voltage transformer. Therefore, the international standards for customer access via narrowband PLC are mostly European-based. The most popular narrowband PLC systems in North America are used within the customer site. The regulatory environment for narrowband PLC differs considerably between Europe and North America. While the Federal Communications Commission (FCC) permits use of any frequency below 540kHz, European Committee for Electro-technical Standardization (CENELEC) defines five different bands ranging up to 148.5kHz. Each of the individual bands has restrictions on its use.	http://www.iec.ch/– IEC; http://www.dlms.com/–DLMS User Association

Integrated Communications			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References***
Ultra Narrowband Power Line Carrier/ Turtle® Automatic Meter Reading System (TS2) by Landis+Gyr	Available now	This technology utilizes existing power lines and patented Ultra Narrow Bandwidth technology to transmit data to and from meters on homes and businesses to the utility for billing and continuous data reporting. The meters are accurate and reliable, and eliminate both the need for a monthly meter visitation by utility employees and the cost associated with that visitation. The Turtle® collects electricity usage and transmits this data via power lines to Turtle receivers in a substation. From the substation, the data is transmitted via modem to the utility for billing and monitoring of the power grid system. The Turtle reads your meter at the same time every month, which eliminates fluctuations in readings that contribute to higher monthly electric bills than expected.	http://www.aclaratech.com/AclaraPLS/pages/default.aspx
WiFi	Available now	WiFi using one of the IEEE 802.11x standards is effective for creating a wireless broadband network, but has a low range of only about 100 meters, thus making regional deployment rather expensive. WiFi provides a lower level of service than conventional coaxial cable or fiber optic service and requires encryption for security. It can be implemented at low cost and may work well with wireless sensors in a substation environment. Data transfer ranges from 5 Mbps to 56 Mbps. State-of-the-art versions employ mesh technology, making these systems very robust for maintaining connectivity even during network component failure. This characteristic makes WiFi technology attractive from an application perspective but, as mentioned previously, the cost to deploy may be unacceptable.	F. Goodman, et.al. "Technical and System Requirements for Advanced Distribution Automation" EPRI Technical Report 1010915, June 2004; Jai Belagur and Tom Lebakken , "Utility Data Communications: New and Emerging Wireless Technologies", *Utility Automation Magazine Article*, May 2006; http://uaelp.pennnet.com/Articles/Article_Display.cfm?Section=ARTCL&ARTICLE_ID=254497&VERSION_NUM=3&p=22
WiMax (4G)	Available now	WiMax can provide requisite long distance communications beyond 10 miles and in some instances beyond 30 miles at data transfer rates of 75 Mbps. WiMax using the IEEE 802.16 standard allows for seamless communication with multiple vendors. WiMax can communicate out of sight via IEEE 802.16e and can communicate with moving trucks or cars. It can serve as the spine of a Transmission and Distribution (T&D) communication system that will support WiFi applications for substation or distribution automation, as well as provide a backhaul infrastructure for AMI systems.	http://www.wimaxforum.org/home/; Jai Belagur and Tom Lebakken , "Utility Data Communications: New and Emerging Wireless Technologies", *Utility Automation Magazine Article,* May 2006; http://uaelp.pennnet.com/Articles/Article_Display.cfm?Section=ARTCL&ARTICLE_ID=254497&VERSION_NUM=3&p=22
Cellular (3G)	Available now	Using the Short Message Service (SMS) function of a digital cellular network can be applied to provide low-cost substation automation to control and monitor substation performance when small bursts of control information or monitoring data is needed; however, SMS of a digital cellular network will not be able to provide the quality of service that on-line substation control and monitoring may require.	T.Tommila, O. Venta, and K. Koskinen, "Next Generation Industrial Automation-Needs and Opportunities," *Automation Technology Review*, 2001; http://www.3gpp.org; http://www.3gpp2.org; http://uaelp.pennnet.com/Articles/Article_Display.cfm?Section=ARTCL&ARTICLE_ID=254497&VERSION_NUM=3&p=22; http://www.wirelessandmobilenews.com/2009/03/sprint_reveals_4g_wimax_plans.html

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Time Division Multiple Access (TDMA) Cellular Wireless (IS-136)	Available now	TDMA, developed by the American National Standards Institute (ANSI)-accredited Telecommunications Industry Association (TIA), is digital transmission technology that allocates unique time slots to each user within each channel. The two major (competing) systems that split the cellular market are TDMA and CDMA. Because of its adoption by the European standard Global System for Mobile communications (GSM) and the Japanese Digital Cellular (JDC), TDMA and its variants are currently the technology of choice throughout the world. However, third-generation (3G) wireless networks will use CDMA, not TDMA.	http://www.tiaonline.org/
Code Division Multiple Access (CDMA)/High-Speed Downlink Packet Access (HSDPA) Cellular Wireless	Available now	CDMA for spread spectrum is one of the technologies chosen for the future generation of wireless systems. The IS-95 based CDMA system developed by the ANSI-accredited TIA has been widely deployed in the United States. IS-95 evolves to CDMA-2000 for third-generation cellular systems. HSDPA is an enhanced 3G mobile telephony communications protocol in the HSPA family— also coined 3.5G or 3G+—which allows networks based on Universal Mobile Telecommunications System (UMTS) to have higher data transfer speeds and capacity. Current HSDPA deployments support downlink speeds of 1.8, 3.6, 7.2, and 14.4 Mbit/s. Further speed increases are available with HSPA+, which provides speeds of up to 42 Mbits/s downlink.	http://www.tiaonline.org/
Very Small Aperture Terminal (VSAT) Satellite	Available now	Satellite can provide new solutions for remote monitoring and control of transmission and distribution (T&D) substations providing extensive coverage. VSAT satellite services are readily available and can be tailored to support substation monitoring; They also provide location and time synchronization (important for successful use of PMUs) based on a global positioning system (GPS). The system can be implemented quickly, but the cost will be high, except for remote locations. Satellite communication can be also affected by severe weather and storms, and have long communication delays for round trips. Several satellite-based services are available. VSAT is the type most often used by utilities. It uses a very small transmitting antenna (0.6 to 3.8 meter) and is star-connected with a hub at the center of the network with dedicated lines running to the host computer. The hub has a large antenna aimed at the satellite. The hub is very expensive and is usually owned by the VSAT vendor.	Y.Hu, and V.O.K. Li, "Satellite-" Internet: A Tutorial," *IEEE Communications Magazine*, vol. 39, pp. 154–162, March 2001
WiFiber	Available now	This system is dubbed "WiFiber" by its creator, GigaBeam, a Virginia-based telecommunications startup. Although the technology is wireless, the company's approach is more of an alternative to fiber optics than to Wi-Fi or WiMax. It is also known as "Optical Wireless." WiFiber systems' speeds from 10 Mbps to 1000 Mbps are possible with ranges above 1 mile.	http://www.gigabeam.com/

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ZigBee Wireless Local/Home Area Network	Available now	ZigBee is a specification for a suite of high-level communication protocols using small, low-power digital radios based on the IEEE 802.15.4-2003 standard for wireless personal area networks (WPANs), such as wireless headphones connecting with cell phones via short-range radio. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPANs, such as Bluetooth. ZigBee is targeted at RF applications that require a low data rate, long battery life, and secure networking. It has become the main driver for Home Area Networks (HAN) in the United States with several major Investor-Owned Utilities (IOUs) selecting ZigBee as their HAN standard. The primary attractiveness of ZigBee is its open standard platform that promises interoperability among multiple products and systems. ZigBee now has a Smart Energy Application Profile that is specifically designed for utility applications within the HAN such as Demand Response, Dynamic Pricing Response, Plug-in Hybrid Electric Vehicle (PHEV) smart charging, etc. The ZigBee Alliance has recently announced a cooperative agreement with HomePlug, which will allow ZigBee-enabled systems to operate seamlessly in a power line carrier or wireless mode. ZigBee uses frequency hopping spread spectrum (FHSS) radio technology, which offers reliable, long-range performance and immunity against jamming and interference.	http://www.rfm.com/products/oem_standalone.shtml; http://www.zigbee.org/Home/tabid/188/Default.aspx
Z-Wave Wireless	Available now	Z-Wave™ is a wireless RF-based communications technology designed for residential and light commercial control and status reading applications such as meter reading, lighting and appliance control, HVAC, access control, intruder and fire detection, etc. Z-Wave is based upon an RF chipset from Zen-sys that provides two-way mesh networking of intelligent devices. The networks communicate via radio at 908.4 MHz in the United States and 868 MHz in Europe. Both are unlicensed bands. Maximum bandwidth is just 9.6K bit/sec but is adequate for the commands sent over the network. The technology can link as many as 232 Z-Wave-enabled devices and adapters in a mesh network along with a controller, such as a handheld remote, that sends out commands. In addition to receiving commands, the chip in each adapter can act as a relay to extend the range of the network. This mesh technology makes it easy to set up and allows for lower power consumption and a low-cost chip.	http://www.z-wavealliance.org/modules/start/; http://www.zen-sys.com/

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Data Over Voice Lines	In use for many years	Voice-grade telephone connections (standard 3 kHz voice circuits) are made either by dialing or by being wired in the telephone company's central office. They remain connected until the service is discontinued. The user has no knowledge of where or how the circuit is routed between the two end-points, unless the telephone company is specifically requested to provide diversity for security and availability purposes. Point-to-point circuits are cost effective for high-speed communication between two devices, but they are more expensive when compared to dial-up applications where the circuit is connected and charged only for the duration of the connection. Digital circuits or Digital Data Services (DDS) can carry data at 2.4, 4.8, 9.6, 19.2, 56, and 64Kbps. Digital circuits are not technically voice-grade, but they can be used to carry either voice or data. Slow-speed leased lines have been used extensively by utilities to provide quick connections to various facilities and devices that cannot otherwise be reached in a structured network or telecommunications scheme.	http://www.rad.com/networks/1994/modems/modem.htm; http://www.techtutorials.info/hdmodems.html; http://www.rad.com/RADCnt/MediaServer/3656_ldv-2.pdf; http://www.vocal.com/data_sheets/v925.html
Asymmetric Digital Subscriber Line (ADSL)	In use for many years	Asymmetric Digital Subscriber Line (ADSL) is the version of this technology that is commonly referred as Digital Subscriber Line (DSL). Its purpose is to connect existing residential telephone customers who use the twisted-pair wired telephone infrastructure to the Internet with higher-than-dial-up data connection speeds. ADSL converts existing twisted-pair telephone lines into access paths for Plain Old Telephone Service (POTS) voice telephone circuits plus simultaneous high-speed data communications. ADSL transmits two separate data streams with much more bandwidth devoted to the downstream leg than the upstream leg, thus the term “asymmetric.” ADSL has a variance of downstream or upstream data speeds depending on the distance between the end use customer and the telephone company’s central office, as well as the condition of that wired infrastructure.	http://www.dslforum.org/; http://www.itu.int/publications/index.html
Cable Modem	In use for many years	The CableLabs Cable Modem project, also known as Data Over Cable Service Interface Specification (DOCSIS), defines standard interface requirements for cable modems providing high-speed data distribution over cable television networks. CableLabs provides services to certify devices to this specification. The DOCSIS specification has been internationally standardized as ITU-T J.112. In Europe, both J.112 and a competing standard called EuroModem are used. The CableHome project has developed interface specifications to extend cable-based services to IP network devices within the home. The CableHome project builds on the DOCSIS connectivity specification to address issues such as device interoperability, user convenience, quality of service, and network management.	http://www.cablemodem.com

Integrated Communications			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References***
Fiber to the Home (FTTH)	Limited adoption; pilot systems under test	FTTH is a technology that provides a broadband fiber-optic connection to consumer sites. FTTH has been the "holy grail" of the telecommunications industry for decades now, promising nearly unlimited bandwidth to the home user. However, until recently the costs of installing that much fiber optic cable and the associated electronics have been prohibitive. Increases in the cost-effectiveness of electronics have helped, but the key enabler of FTTH is the Passive Optical Network (PON). PON technology permits a single fiber to be split up to 128 times without active electronic repeaters. This creates a point-to-multipoint network that does not require any electronics between the consumer premises and the central office. A few telephone companies have deployed point-to-point fiber networks to supply FTTH. Others have connected PONs to neighborhood data concentrators called Optical Network Units (ONUs), creating Fiber to the Curb (FTTC) systems that may use either copper or fiber for the last connection to the customer. Still, such systems have inherently higher costs than a point-to-multipoint PON.	http://www.ftthcouncil.org – FTTH Council; http://www.fsanweb.org – Full Service Access Network (creators of APON)
Paging Networks	Worldwide adoption	Paging networks are radio systems for delivering short messages from the telephone system or Internet to—and sometimes from—small, remote, mobile terminals. Paging systems use a variety of technologies, including microwave and satellite. Like cellular systems, virtually all of the paging networks use more than one transmitter. Unlike cellular systems, they usually rely on simulcast capability to blanket an area. Several transmitters must send the same message over a wide area using the same frequency. A system controller applies sophisticated scheduling algorithms to manage the frequency spectrum used by the system. Some paging standards exist, such as Post Office Code Standard Advisory Group (POCSAG), or European Radio Messaging System (ERMES) in Europe, but many systems remain either proprietary or licensed. Fortunately, paging systems typically provide a variety of open standard gateways in and out of the system, including direct serial, dial-up, and e-mail.	http://en.wikipedia.org/wiki/Pager; http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=529441
Radio Frequency Identification (RFID)	Early adoption	RFID is a technology that uniquely identifies an object, animal, or person incorporating the use of electromagnetic or electrostatic coupling in the RF portion of the electromagnetic spectrum. RFID is coming into increasing use in industry as an alternative to the bar code. The advantage of RFID is that it does not require direct contact or line-of-sight scanning. An RFID system consists of three components: an antenna, transceiver (often combined into one reader), and a transponder (the tag). The antenna uses RF waves to transmit a signal that activates the transponder. When activated, the tag transmits data back to the antenna. The data is used to notify a programmable logic controller that an action should occur.	http://www.usingrfid.com/

Integrated Communications			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References***
Multiple Address System (MAS) Radio	Broad utility deployment in United States	A basic MAS radio link consists of a master radio transmitter/receiver unit and multiple remote radio transmitter/receiver units. A master unit can access or poll multiple units via a pair of transmit/receive frequencies. The master unit is set up prepared to transmit and receive, thereby keeping transmitter keying delays to a minimum. Each remote unit is set up in the listening mode until it is polled and made ready to transmit. Each remote unit has a unique address so no two units will try to answer the poll at the same time. This eliminates any contention among the remotes to transmit to the master. The frequency pair used by MAS is licensed by the FCC, and the same pair can be re-used elsewhere in the system as long as it does not cause any interference. For difficult-to-reach locations due to topography or limitation of line-of-sight, the same MAS radio can be used as a repeater radio to allow signal transmission over or around large obstructions. MAS radio is the preferred communication medium and has been used widely by utilities for SCADA and DA systems.	http://www.micronetcom.com/
Spread Spectrum (SS) Radio System	Available now	To avoid having to operate with allocated frequencies from the FCC, a different type of radio known as SS radio is used in point-to-multipoint radio systems. The configuration of the master and remote radios is exactly the same as that for the MAS. The only difference is that FCC Part 15 Rules allow these radios to operate without the need for a license in the 902-928MHz frequency band. To meet the FCC criteria, the radios must operate at low power and must continually hop over a range of frequencies (typically 64 or more), staying on one frequency only for a short fixed period (typically 250 ms). Special built-in processing allows the radio to recover data in its original format while continually changing frequencies.	http://www.conformity.com/; http://grouper.ieee.org/groups/802/11/main.html; http://www.sss-mag.com/ss.html
Internet Protocol Version 4 (IPv4) Core Networking	Available now	IPv4 is the original network layer for the Internet suite of protocols (RFC 791, STD0005). Its primary characteristics arise from the structure of its four-byte address space that was originally intended to (and still does) to provide some information on how a message should be routed. Addresses with the same prefix share a subnet and do not need to be forwarded; addresses with different prefixes must be forwarded elsewhere. This simple routing decision makes it easy to implement end devices.	http://www.isoc.org/ – Internet Society; http://www.ietf.org/ – Internet Engineering Task Force; http://www.iana.org/– Internet Assigned Numbers Authority; http://www.rfc-editor.org/– Request for Comments archive (standards documentation).
Internet Protocol Version 6 (IPv6) Core Networking	~2 Years	IPv6 (RFC 2460), developed by the Internet Area of Internet Engineering Task Force (IETF), is a new version of the Internet Protocol, designed as a successor to IPv4 (RFC-791). The primary changes are (1) an extension of the IP address from 32 bits (IPv4) to 128 bits (IPv6) to enable more addressable nodes; (2) flow labeling; (3) header simplification; and (4) more support for extensions and options. Support of security services such as message authentication and encryption is also required for any implementation of IPv6. Advantages/Strengths: IPv6 has increased address space and has many improvements in areas such as routing and network auto-configuration over IPv4. Disadvantages/ Weaknesses: Because of the enormous investment in IPv4, and the limited additional benefits of IPv6, the latter version has not yet been implemented widely, nor has much progress been made in convincing vendors of the need to convert from IPv4 to IPv6.	http://www.ipv6forum.com/

Integrated Communications			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References***
AGA-12 Cryptographic Protection of SCADA Communications General Recommendations	2–5 Years	The American Gas Association (AGA) represents almost 200 local utilities that deliver natural gas to homes in the United States. These utilities are part of the critical infrastructure and rely on SCADA networks to control the operations. AGA, in conjunction with the Gas Technology Institute (GTI) and other industry groups, created AGA 12 to develop cyber security standards and protocols for the industry. AGA 12 has taken a unique approach to focus on securing the communications link between field devices and the control servers or control center. While there certainly is a risk of data insertion and modification in the communication channel, it may not be the most likely or even easiest avenue of attack on a SCADA system. The first technical report, TR-1, defines an add-on encryption module that also could be integrated into a Remote Terminal Unit (RTU) or PLC.	http://www.aga.org
Virtual Private Groups (VPG) Technology	Available now	VPG technology enables endpoint-to-endpoint encryption of network traffic that addresses the threat of malicious insiders. It also reduces external threats and enforces only authorized communications between organizational and other groups to prevent mistakes. VPG does not require a supporting public key infrastructure, making it superior to virtual private networks (VPNs).	Adventium Labs; http://adventiumlabs.org; Brian Isle, Brian.Isle@AdventiumLabs.org
Integrated Digital Enhanced Network (IDEN)	Available now	IDEN has five integrated services in one single device, giving users more choices on how to communicate. It is a true wireless network approach and provides two-way radio customers with many advantages not found on older specialized mobile radio (SMR) systems. IDEN technology utilizes highly spectrum-efficient radio transceivers to digitize and process high volumes of voice and data through a single channel. Trilliant and Motorola Introduced and co-developed IDEN®-based communications solutions for advanced energy meters.	http://www.motorola.com/mediacenter/news/detail.jsp?globalObjectId=9575_9504_23;http://idenphones.motorola.com/iden/home.jsp?content=tech&country=us
Wavenis Wireless	Available now	Like ZigBee and Z-Wave solutions, Wavenis enables real-time remote monitoring and control of a wide range of parameters either under the watchful eye of computer automation or human intervention. Wavenis wireless technology is finding its way into applications such as power consumption meters, residential gateways, home automation devices for lighting and mechanical control, temperature and humidity monitoring and control devices, level monitors for volume and pressure, and handheld computing devices for data collection and inventory control. It has a range up to 200m and can achieve a data rate of 4.8 kbps to 100kbps.	http://mobiledevdesign.com/hardware_news/wavenis_wants_time_1023/; http://www.wavenis-osa.org/

Table 1: Integrated Communications

ADVANCED COMPONENTS

Table 2: Advanced Components

Advanced Components			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Current Limiting Conductor (CLiC)	2 Years	The CLiC distributed series impedance device is low cost ($15 to $30/kVAr) and can remotely operate with preprogrammed logic at each CLiC device to inject or remove series impedance. The CLiC is a commoditized module and is coupled to the line at a transmission or sub-transmission tower. It can also control the flow of power and has the potential to balance the flow between phases and between parallel lines, reducing transients and maximizing use of T&D assets. This modular device is being tested at 161 kV at Georgia Tech's National Electric Energy Testing Research and Applications Center (NEETRAC) for Tennessee Valley Authority (TVA). More modules are being produced and will be tested in the field through collaborated funding provided by DOE, TVA, Consolidated Edison of New York (ConEd), and National Rural Electric Cooperative Association (NRECA). It promises important system-wide benefits including increased line and system capacity utilization; increased reliability; improved operation under contingencies; incremental deployment; and rapid implementation. It will be autonomous and not require communication with the device.	http://www.ipic.gatech.edu/research.html; http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=1668661
Smart Wires Class of Distributed Series Impedance (DSI) Device	3–4 Years	The Smart Wires DSI device is estimated to be low cost ($20–$40/kVAr) when mass produced. The modular device can inject or remove series impedance, control the flow of power either with wireless or PLC, and can balance the flow between phases and between parallel lines, reducing transients and maximizing use of T&D assets. The Smart Wires DSI is a commoditized module coupled to the line at a transmission or sub-transmission tower. It can also monitor line conditions such as thermal rating, vibrations, icing, etc.	http://www.ipic.gatech.edu/research.html, GATECH Intelligent Power Infrastructure Consortia (IPIC)
Improved HVAC Bundle Designs for Lowering Impedance and Electro-Motive Force (EMF) (>345 kV)	1 Year	Tennessee Technology University did an electromagnetic field study in the late 1990s for TVA to design bundle configurations that can reduce EMF in >500 kV lines that are optimized and more compact by using additional lines (such as 4 x 5 x 4 versus the current 3 x 3 x 3 configuration). They found that the line impedance can be reduced by 50%, ATC increases by 50%, and EMF decreases by 70%; however, the switching surge safety is reduced. A report was completed for TVA in the late 1990s that reviewed Russian low impedance and low EMF designs and developed new designs for possible use by TVA. In addition, Brazil now uses High Surge Impedance Lines (HSIL) that can theoretically reduce series reactance and natural line capacity by up to 200%. Brazil has two 255 km HSIL at 230 kV that increase the surge impedance load (SIL) by 60%, and a 1600 km HSIL at 500 kV with a 40% increase in SIL and line capacity.	Tennessee Technology University oregis@chesf.gov.br

Advanced Components			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Controllable Network Transformer (CNT)	1–3 Years	GATECH IPIC has developed a CNT in the lab that can achieve both dynamic grid voltage and power flow control. Desired dynamic control of the asset is realized using a thin AC converter (TACC) that consists primarily of commercially available power semiconductors and high-frequency filter elements, with minimal energy storage located between the grid and the network transformer. A TACC can be retrofit to pole-mounted distribution voltage capacitors providing nearly instant dynamic voltage control to mitigate local voltage collapse or fault-induced delayed voltage recovery and power flow control.	http://www.ipic.gatech.edu/research.html, GATECH Intelligent Power Infrastructure Consortia (IPIC)
High Temperature Superconducting Synchronous Condenser (HTSCC)– SuperVAR with 2G YBCO HTS Wire	3–6 Years	In shunt, HTSCC with 2G wire can provide even lower cost voltage support than 1G SuperVAR® dynamic synchronous condenser. It also can provide distributed, small, modular dynamic reactive power compensation with 2X to 4X peak output for short periods of time without harmonics. In series, HTSCC can provide dynamic, moderate-cost power control. The 2G system should be able to provide higher output at lower cost than a 1G system, as the 2G system could be all superconducting with a low-loss filamentized 2G wire stator instead of a copper stator. The 2G SuperVARtm has the potential to be >99% reliable with only 0.5% losses.	http://www.ornl.gov/
HTS Fault Current Limiters (FCL) Using 2G Wire	3–6 Years	2G wire is made of Yttrium Boron Copper Oxide. FCLs can be developed that have 10X less AC losses, are instantaneous, limit currents by 3X to 10X, and have small footprints.	AMSC, SuperPower; http://www.ornl.gov/; SC Power Systems, Inc.
Short Circuit Current Limiter-(SCCL)	Available now	Siemens has an SCCL that uses thyrister switches to bypass a series capacitor that is tuned with a series reactor, enabling the SCCL to throw the series reactor into the circuit to reduce fault currents.	https://www.energy-portal.siemens.com/static/de/de/products_solutions/12793_106977_short%20circuit%20current%20limitation%20sccl.html
Flow Control Using HTS Cable	Available now	Very low impedance (VLI) circuit that, with a small, low cost 5% phase angle regulator (PAR), can relieve congestion on parallel circuits and control the power flows within a network.	http://www.amsuper.com/products/transmissionGrid/104273030481.cfm
D-VAR or DSTATCOM	Available now	D-VARs or DSTATCOMs are mobile and relocatable. They use insulated gate bipolar transistors (IGBTs) that are air cooled, and operate at high efficiency which results in low harmonics. D-VARs or DSTATCOMs can be sited at T&D interfaces or at an industrial interface to provide voltage support, reduce industrial flicker generation, provide improved power quality, mitigate wind generator impact on transmission lines, etc. The D-VARs have the capability to peak their output at 3X to 4X rated capacity before returning to their nominal rating, which is important for managing flicker, voltage instabilities, and fault-induced delayed voltage recovery (FIDVR). The cost on a per kW peak rating can be 3X to 4X lower than on a nominal rating.	http://www.amsuper.com/products/transmissionGrid/104273030481.cfm; http://www.sandc.com/products/purewave/dstatcom.asp
Static Shunt Compensator (STATCOM)	Available now	STATCOM is for dynamic voltage support in a quarter cycle. Typical costs can range from $125/+-kVAr to $150/+-kVAr depending on the level of redundancy and reliability required. San Diego Gas & Electric (SDG&E) has installed a Mitsubishi STATCOM. A STATCOM made from a Gate Turn Off (GTO) Thyristor can operate at 25% over capacity for a few seconds.	Mitsubishi, Siemens, ABB, Areva, http://www.eere.energy.gov/de/facts.html; http://library.abb.com/GLOBAL/SCOT/scot235.nsf/VerityDisplay/4EDF68B14B79751F85256C550053D6B6/$File/Hard-to%20Find%2019c.pdf

Advanced Components			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Static Synchronous Series Compensator (SSSC)	Available now	The SSSC is a solid-state voltage source inverter connected in series with the transmission line through an insertion transformer. This connection allows the SSSC to precisely control power flow in the line under a wide range of system conditions.	www.areva.com; http://ieeexplore.ieee.org/Xplore/login.jsp?url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel4%2F61%2F14462%2F00660884.pdf%3Farnumber%3D660884&authDecision=-203
Solid State Transfer (SST) Switches	Available now	SSTs are available now to provide customers uninterruptible power from two independent feeders.	http://library.abb.com/GLOBAL/SCOT/scot235.nsf/VerityDisplay/4EDF68B14B79751F85256C550053D6B6/$File/Hard-to%20Find%2019c.pdf (page 18)
SiC ETO Based Solid State Transformer	5–7 Years	Silicon Carbide Emitter Turn-Off Thyristor (SiC ETO) transformer at medium voltage would have no transformer oil and could generate VARs as needed.	http://www.spec.ncsu.edu/
Annealed Aluminum Steel Support (ACSS) with Trapezoidal Wire (TW) or ACSS/TW	Available now	ACSS supported with trapezoid cross section conductor wire (TW) can carry 32% more current, reduce line losses at normal loads, and can be handled as normal Aluminum Conductor Steel Reinforced (ACSR) conductor wire. However, the ACSS/TW is heavier than ACSR, which may require upgrades to the electrical towers.	General Cable, http://www.southwire.com/welcome.jsp
Aluminum Conductor Composite Reinforced (ACCR) And Aluminum Conductor Composite Core (ACCC)	Available now	ACCR costs may be multiple times the costs for a standard ACSR conductor, but can increase transmission thermal capacity up to 85%. Composite Technology Corporation's (CTC's) ACCC configured with TW is expected to cost perhaps multiple times the costs for standard ACSR with a >55% capacity increase. As the ACCC temperature increases with line current, there will be little line sag. The 3M ACCR can operate up to 240 °C, while the ACCC is limited to 175 °C.	3M, CTC, http://www.southwire.com/welcome.jsp
Southwire Annealed Aluminum Conductor Steel Supported (ACSS) Trapezoidal Wire (TW) with High Strength Steel (HS) at 285 ksi Tensile Strength	Available now	Southwire's ACSS/TW with high strength steel (HS) at 285 ksi tensile strength (HS285 ACSS/TW) can carry 62% more current than a standard ACSR conductor, reduce line losses at normal loads due to the higher aluminum content, and can be handled as normal ACSR conductor wire. It is slightly more expensive than normal ACSR wire. It is slightly higher in weight, combines the attributes of the proven ACSS and ACSS/TW with a higher strength core for optimal performance, and provides good value for re-conductoring a line that is approaching overload conditions. It is made from extra-high-strength zinc-5% aluminum-mischmetal alloy-coated high carbon steel core material (Galfan). It utilizes existing steel knowledge resulting in high tensile strength without loss of elongation, ductility, or stress corrosion properties. However, because the HS 285 ACSS/TW is heavier than ACSR, upgrades to the towers may be required. The temperature limit for the HS 285 ACSS/TW is 196 °C.	http://www.southwire.com/welcome.jsp

Advanced Components			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
1G HTS Cables	2–3 Years	HTS cables for Medium Voltage Direct Current (MVDC) applications can be used to transmit high currents underground or undersea with no loss and large quantities of power at reduced voltages (lower voltages reduce High Voltage Direct Current [HVDC] terminal costs by 25%–50%). Very low heat release allows small trenching requirements. HTS MVDC cables can reduce urban transmission congestion or allow for more intensive urban development. They allow offshore, high-capacity factor, economic wind generators. It may be competitive with underground cables using large quantities of high-priced copper.	http://www.ornl.gov/; http://www.amsc.com/products/htswire/HTSCables.html; https://www.energy-portal.siemens.com/irj/portal/ptd/public/en/global-01/home_ext
2G HTS Cables	3–5 Years	Six times higher critical densities can be achieved with 2G wire (YBCO or Yttrium Boron Copper Oxide) versus those achieved with 1G wire while both operating at liquid nitrogen temperatures. YBCO can withstand much higher critical magnetic fields. Low AC loss can be demonstrated with filamentized 2G wire. Prices for 2G wire are estimated to be 3X to 10X cheaper than 1G wire and have 10X lower AC losses.	http://www.ornl.gov/; http://www.amsuper.com/products/htsWire/HTSCables.cfm; https://www.energy-portal.siemens.com/irj/portal/ptd/public/en/global-01/home_ext
IntelliRupter® PulseCloser	Available now	To test for faults, PulseClosing applies a very fast, low-energy pulse to the line, significantly reducing damaging fault currents and voltage sags on the faulted line as well as adjacent feeders. Substation transformers will experience fewer through-faults, extending their life. Cables, overhead conductors, splices, and terminations will also experience less thermal and mechanical stress from through-fault currents.	http://www.sandc.com/products/intellirupter/default.asp
Advanced OLTC for Transformers	1–2 Years	Conventional tap changers are designed to keep the voltage on the low voltage side within certain limits around the set point. When the transmission side voltage decreases, traditional on-load tap changers adjust the output and draw more reactive power from the weakened transmission system. Intelligent on-load tap changers use both HV and LV values and perform an advanced tap changing control.	http://library.abb.com/global/scot/scot296.nsf/veritydisplay/899e52a1c85c4fefc12574b1002c96c7/$File/SA2006-000024_A_en_Advanced_OLTC_Control_to_Counteract_Power_System_Voltage_Instability.pdf
FACTS Dynamic Brakes	Available now	A dynamic brake is used to rapidly extract energy from a system by inserting a shunt resistance into the network. Adding thyrister controls to the brake permits the addition of control functions, such as on-line damping of unstable oscillations. BPA has installed a dynamic brake on its system.	http://certs.lbl.gov/ntgs/issue-6.pdf (pg F-38); http://phasors.pnl.gov/resources_standards/WAPS_WPRC04.pdf (pg. 21, 22)
Unified Power Flow Controller (UPFC)	Available now	A UPFC is a STATCOM plus an SSSC for power flow control. It requires a very specialized series transformer for the SSSC operation. A UPFC can provide all dynamic voltage support, all power flow control, or a combination, but it is expensive. AEP has installed a 138 kV UPFC.	https://www.energy-portal.siemens.com/irj/portal/ptd/public/en/global-01/home_ext; http://www.eere.energy.gov/de/facts.html
Convertible Static Compensator (CSC)	Available now	A CSC is a UPFC that also has an interline power flow controller for bypassing transmission congestion at a substation or interface. (Applied at NYPA's Marcy substation.)	https://www.energy-portal.siemens.com/irj/portal/ptd/public/en/global-01/home_ext; http://www.eere.energy.gov/de/facts.html

Advanced Components			
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One Cycle Control Controllers	Available now	One Cycle Control controllers deliver a paradigm shift in active 3-phase power conversion (no digital signal processors and no software) that enables reduced complexity; rapid dynamic response; global stability; high reliability for FACTS (STATCOM, DSTATCOM, UPFC, UPQC); unity power factor active AC/DC converters; Active Power Filters (APFs); inverters; and advanced transformers. These devices are the size of a business card.	One-Cycle Control, Inc.; http://www.onecyclecontrol.com
Medium Voltage Static Transfer Switch (MVSTS)	Available now	The MVSTS is designed to provide whole facility power outage and voltage sag protection as a low-cost alternative to large industrial UPS systems when a dual distribution feeder service is available.	http://www.satcon.com/; https://www.energy-portal.siemens.com/irj/portal/ptd/public/en/global-01/home_ext; Areva, ABB, Mitsubishi, AMSC, S&C Electric
Advanced Emitter Turn Off (ETO) Thyristor Switch	In R&D	Semiconductor Power Electronics Center (SPEC) is pursuing the advanced 4G ETO Thyristor based on silicon and the 5G ETO based on SiC to improve power electronic device performance and reduce cost. A 4G ETO small distributed FACTS device is being designed for a 10 MVA distributed FACTS application (like flicker control for a BPA wind farm), an SSSC to control power flow, and a power electronic transformer that uses 5G ETOs based on SiC.	NCSU Semiconductor Power Electronics Center (SPEC), Dr. Alex Huang, aqhuang@ncsu.edu
Advanced Materials	In R&D	Advanced materials research is being done in various areas including: (1) chemical vapor deposition of diamond tips in a vacuum to create a field effect transistor (DVFET) with 10X voltage and current capabilities that is capable of operating at 500 °C, (2) use of nano-diamond powder with transformer oil to increase oil thermal conductivity and transformer ratings, and (3) use of electrically doped diamond dust with copper and tungsten sintered to make erosion-resistant and high-temperature circuit breaker contacts and transformer load tap changers for voltage regulating transformers.	Vanderbilt University, Dr. Jim Davidson, jld@vuse.vanderbilt.edu
Medium Voltage Static Voltage Regulator (MVSVR)	Available now	The MVSVR boosts the whole-facility load voltage during source voltage sags caused by faults in the utility distribution grid or in the transmission system. The load voltage boost is performed within a quarter to half cycle, enabling even the most sensitive facility equipment to ride through sag events without operational disruptions.	http://www.satcon.com/; https://www.energy-portal.siemens.com/irj/portal/ptd/public/en/global-01/home_ext; Areva, ABB, Mitsubishi, AMSC, S&C Electric
Thyristor-Controlled Series Compensators (TCSC)	Available now	TCSCs are an extension of conventional series capacitors made by adding a thyristor-controlled reactor. Placing a controlled reactor in parallel with a series capacitor enables a continuous and rapidly variable series compensation system. The main benefits of TCSCs are increased energy transfer, dampening of power oscillations, dampening of subsynchronous resonances, and control of line power flow.	ABB, AREVA, Mitsubishi, etc.
Static Var Compensator (SVC)	Available now	SVCs, the most important FACTS devices, have been used for a number of years to improve transmission line economics by resolving dynamic voltage problems. Their accuracy, availability, and fast response enable SVCs to provide high-performance steady state and transient voltage control compared with classical shunt compensation. SVCs are also used to dampen power swings, improve transient stability, and reduce system losses by optimizing reactive power control.	ABB, AREVA, Mitsubishi, etc.

Advanced Components			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Plug-in Hybrid Electric Vehicle (PHEV)	2–5 Years	While it appears that PHEVs are much better suited for short-term ancillary services such as regulation and spinning reserve, a large fleet of PHEVs could possibly replace a moderate fraction (perhaps up to 25%) of conventional low-capacity factor generation for periods of extreme demand or system emergencies. Overall, the ability to schedule both charging and very limited discharging of PHEVs could significantly increase power system utilization.	Technical Report NREL/TP-620-40293
EESTOR	1–2 Years	EESTOR has developed an advanced barium titanate energy storage device based on circuit film technology. The target market is batteries for hybrid electric vehicles, but it can be built for cell phones and in sizes up to 52 kWh. The storage device can quickly charge and discharge in 15 minutes, and can cycle over a million times. Potential concepts include charging plug-in hybrids during off-peak periods to increase loads. The storage devices would then be managed by intelligent agents or the transmission dispatch center to discharge into the distribution system—when hooked up—during emergencies or during high-cost peak periods.	http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=7033406.PN.&OS=PN/7033406&RS=PN/7033406
Sodium Sulfur (NaS) Batteries	Available now	NaS batteries are now available for up to 8 hours for about $3000/kW for load following and peak shaving, and can be used for voltage and transient stability support and customer ride-through. Shaving the peak can avoid the need for new substations or second transformer banks. NaS battery technology has been demonstrated at over 190 sites in Japan, totaling more than 270 MW with stored energy suitable for 6 hours daily peak shaving. The largest NaS installation is a 34 MW, 245 MWh unit for wind stabilization in Northern Japan. Utilities in the United States have deployed approximately 9MW of NaS batteries. The cycle life for the NaS batteries is about 5,000–6,000 cycles, which may limit their life if they are charged and discharged once or twice every day (10–15 year life).	http://www.ngk.co.jp/english/news/2009/0204.html; http://www.electricitystorage.org/tech/technologies_technologies_nas.htm; http://www.vrbpower.com/ with 995 SI sq m needed per 10 MWs for 8 hours
ZnBr Batteries	Available now	Premium Power Corporation (PPC) has developed low cost (<$200/kWh) batteries that have cycle lives of >100,000 hours, low environmental impacts, and high energy densities. The batteries are UL- and FEMA-certified, modular, and available in 45 kW to 500 kW sizes with 4–7 hours of storage; 10 MW units with 5–7 hours of storage are being designed. Over the last few years, 150 kW units with 1.5 hours of storage have been installed, and a TransFlow 2000 (500 kW and 5 ½ hours) has been shipped. A TransFlow 2000 today is priced at $850,000 installed for 5 ½ hours of storage ($1700/kW) and will be mobile on a trailer. With the addition of an extra electrolyte, the TransFlow unit will not be readily mobile, but will have 7 hours of storage (3.7 MWh), with a cost of $910,000 or $1,800/kW, making it the cheapest advanced battery with a long cycle life. PPC is now developing a small 10 kW, 5-hour battery for residential application, which would be perfect for load management, smart grid applications, etc.	http://www.premiumpower.com/' Bic Stevens at Bstevens@premiumpower.com

Advanced Components			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Xtreme Power Advanced Batteries	Available now	Proprietary power cell technology with a current cycle life of 2,500 cycles is expected to grow to 8,000 cycles, with claims of low capital costs. The technology is not well capitalized at this time, but Xtreme Power claims to be building a 15 MW and 10 MWh XP battery storage system—costs appear high at about $450/kW-hr as compared to $200/kW-hr for the PPC ZnBr. Very high efficiencies of >90% have also been claimed.	ccoe@xtremepowersolutions.com; www.xtremepowerinc.com
25 kWh Beacon Flywheel	Available now	Beacon 25kWh flywheels can be used for voltage and transient stability support and customer ride-through. With a 100 kW inverter, the projected cost is $1000/ kW per 15 minutes. Applications include frequency regulation, angular instability control, and ramp mitigation.	http://www.beaconpower.com/products/EnergyStorageSystems/SmartEnergy25kWh.htm; http://www.beaconpower.com/products/EnergyStorageSystems/SmartEnergyMatrix.htm
Grid Friendly Appliances (GFA)	1–3 Years	GFAs mount in household appliances and are sensitive to change in frequency and voltage. They can be configured to take autonomous control or can be dispatched. Implementing controllable GFAs could be a low-cost solution to mitigate system collapse and blackouts.	http://availabletechnologies.pnl.gov/
Thermal Energy Storage	Available now	Off-peak electricity can be used to make ice from water. The ice can then be stored until the next day when it is used to cool either the air in a large building (thereby shifting that demand off-peak) or the intake air of a combustion gas turbine generator (thereby increasing the on-peak generation capacity).	http://www.energy.ca.gov/distgen/equipment/energy_storage/energy_storage.html
Hybrid DER	3–5 Years	Hybrid DER (e.g., solid oxide fuel cell combined with a microturbine) is expected to be less costly ($1200/kW to $1500/kWw) than a fuel cell ($3,000/kW to $4,000/kW) and more expensive than the microturbine {$900/kW to $1,000/kW}, but can achieve efficiencies of 65%–80% or more.	http://www.energy.ca.gov/distgen/equipment/energy_storage/energy_storage.html; http://www.eere.energy.gov/de/, Siemens, Fuel Cell Energy, etc.
Multiple Distributed Generation (DG) Types	Available now	Various types of Distributed Generation, such as photovoltaic systems, fuel cells, micro-turbines, reciprocating engines and small wind power systems exist today.	http://www.distributed-generation.com/
Microgrids	1–2 Years	Microgrids are an application of distributed energy (DE) devices and control systems. They enable a set of generators, storage devices, and load-reduction technologies to reliably supply the entire electricity demand of a grid-isolated group of customers.	http://www.eere.energy.gov/de/minigrids.html
Power Parks	Available now	Power parks (also called "premium power parks") are an alternative to the traditional approach. They may include uninterruptible power supplies such as battery banks, ultracapacitors, or flywheels. They typically include an on-site power source to increase reliability.	http://www.eere.energy.gov/de/power_parks.html
Direct Current (DC) Microgrid	3–5 Years	Another concept for future power grids is to set up neighborhoods that run entirely on DC lines, which would interface with the rest of the grid through DC-to-AC converters.	http://www.eere.energy.gov/de/dc_microgrids.html

Advanced Components			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Electric Load as a Reliability Resource	Available now	The use of normally passive loads to act as dynamic resources is a method for managing system reliability. Demand response applications controlled by system operators is an example of this method.	http://www.eere.energy.gov/de/electrical_load.html
Microgrid Fast Switch	2–3 Years	The Microgrid Fast Switch enables fast intentional islanding and automatic re-synchronization, but it is currently a high cost.	http://der.lbl.gov/seminars/ChrisMarnay021203.pdf
Customer-Based DER	Available now	Some examples of customer-based DER include plug-in hybrid electric vehicles (PHEV), fuel cells, integrated load control, grid-friendly appliances, etc.	Generic
Demand Response Business Network (DRBizNet)	Available now	This is an integrated infrastructure for Demand Response (DR) that can be implemented in a distributed manner and drastically increase performance of DR business processes.	Utility Integration Solutions, Inc.; http://www.uisol.com
Island Renewables	3–5 Years	This technology focus includes renewable DE (e.g., wind, solar, geothermal, ocean, hydrogen, thermal, waves), bulk energy storage (e.g., batteries, hydro), hydrogen storage, and biomass technology.	Hawaii Distributed Energy Resources Technologies for Energy Security
DER Characterization	3–5 Years	This project involves the development and investigation of a power grid test bed in Playas, NM, for grid modeling and DE characterization. Research will characterize distributed energy resources in terms of their capacity to reliably serve disparate local loads and support the performance of the grid. Specific research will be conducted in the following areas: synthesis of catalytic membranes for the conversion of sugars and alcohols to hydrogen (biomass), development of composite membranes for high-temperature CO_2/H_2 separations, and methods for manufacturing low-cost photovoltaics.	http://www.nmt.edu/research/index.htm; New Mexico Tech Power Grid Reliability and Renewable Energy Research
High Power Lab	1–3 Years	The project is a feasibility study that will research, engineer, and demonstrate high-power laboratory testing protocols to accurately reproduce conditions on the electric power grid representing both normal load switching and abnormalities such as short-circuit fault protection. Test circuits, equipment, and techniques will be developed and proven at reduced power levels to determine the feasibility of building a large-scale high-power testing laboratory. The project will deliver demonstrated testing techniques, high-voltage test equipment for load and simulation testing, and recommended designs for future implementation of both a high-power testing laboratory to test equipment and systems to simulate the transmission grid (230kv).	http://www.sandc.com/
Variable Frequency Transformer (VFT)	Available now	The VFT is a controllable, bidirectional transmission device that can transfer power between asynchronous networks. Functionally, the VFT is similar to a back-to-back HVDC converter.	http://www.gepower.com/prod_serv/products/transformers_vft/en/variable_frequency.htm

Advanced Components			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Matrix Fault Current Limiter (MFCL)	Available now	MFCL is developed by Intermagnetics General. The $12.2 million project has been funded by the DOE and Electrical Power Research Institute (EPRI). When a surge pushes the amount of current above a particular energy level, resistance in the superconducting material increases; this increased resistance then turns some of the electrical energy into heat, thereby reducing the power flow. The main applications of MFCL includes accommodation of new generation facilities, distributed generation and IPP hookups, and power imports without having to upgrade existing grid protection equipment.	http://www.global-change.com/files/pdf/Superconductivity%20Research%20Paper.pdf; http://my.epri.com/portal/server.pt?space=CommunityPage&cached=true&parentname=ObjMgr&parentid=2&control=SetCommunity&CommunityID=404&RaiseDocID=000000000001008697&RaiseDocType=Abstract_id
Superconducting Magnetic Energy Storage System (SMES) Distributed SMES (D-SMES)	Available now	SMES is a device for storing and instantaneously discharging large quantities of power. Some of these systems are already in use for assisting large industrial customers with voltage stability and power quality problems. D-SMES System is similar to the SMES but is designed for utilities to improve system-level reliability and transfer capacity. The D-SMES system also reduces the need to put up more power lines, which leads to greater efficiency in power usage and provides cost-effective power stabilization.	http://www.amsc.com/index.html

Table 2: Advanced Components

ADVANCED CONTROL METHODS

Table 3: Advanced Control Methods

Advanced Control Methods			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Distributed Intelligent Control Systems (Multi-Agents)	Available now	A multi-agent system is a system composed of multiple interacting intelligent agents. Multi-agent systems can be used to solve problems, which are difficult or impossible for an individual agent to solve. There are many applications of the multi-agent system in power systems to explore such as Autonomous Fault Detection and Reconfiguration, Power Markets, Protection and Co-ordination, Reactive Power Control, etc.	An Introduction to Multi-Agent Systems, Wooldridge, Michael, John Wiley and Sons, 2002; http://dsonline.computer.org/portal/site/dsonline/menuitem.20d6846e1c7ed783f1a516106bbe36ec/index.jsp?&pName=dso_level1_home&path=dsonline/content&file=about.xml&xsl=generic.xsl; http://multiagent.com/
Distributed Intelligent Control Systems (Agents)	Available now	Distributed intelligent control systems are adaptive, self-aware, self-healing, and semi-autonomous control systems using parallel and distributed processing. Distributed computing is parallel computing using multiple independent computers that communicate over a network to accomplish a common objective or task.	http://www.infotility.com/; http://www.ieee.org/portal/site; http://www.computer.org/portal/site/transactions/menuitem.a66ec5ba52117764cfe79d108bcd45f3/index.jsp?&pName=tpds_home/about.htm&
Substation Automation (SA)	Available now	SA is the integration of smart sensors with integrated communication technologies to enable real-time monitoring and control of substation equipment.	Vendor Sites
Advanced SCADA	Available now	Advanced Control System's PRISM™ SCADA integrates additional functions to standard SCADA such as tagging, alarms, advanced user interface, load management, and short-term load forecasting.	http://www.acsatlanta.com/
SMP Gateway	Available now	SMP Gateway is an advanced substation gateway that implements all the following functions required for device integration at the substation-level: protocol converter, data concentrator, terminal server, automation processor, and time synchronization.	Cybectec Inc.; http://www.cybectec.com/
Distribution Automation (DA)	Available now	DA is the integration of smart sensors with integrated communications technologies to provide real-time reconfiguration of distribution equipment to prevent customer outages and minimize time of disruption.	Vendor Sites
Intelligrid Transmission Fast Simulation and Modeling (T-FSM) –	> 3 Years	The EPRI Intelligrid T-SFM system is based on a high performance distributed autonomous real-time (DART) control system using the latest available technologies. The plan is to embed intelligent devices to enable improved monitoring and control through innovations in prediction, sensing, modeling, analysis, and optimization using wireless sensors, new PMUS, etc. The architecture for a DART system has been developed.	http://www.epriweb.com/public/000000000001012148.pdf; Transmission Fast Simulation Modeling (T-FSM)-Architectural Requirements EPRI Report 1011667, March 2005

Advanced Control Methods			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Waveform Analysis (Power Quality, etc.)	> 1 Year	This task will provide a state-of-the-art assessment of standards and current technologies being used for advanced monitoring systems, fault location, fault prediction, and fault analysis. Important assessments will include the following: (1) standards for sharing monitoring data (e.g., PQDIF, Comtrade) capabilities of different monitoring system platforms; (2) sensor technologies and application; (3) database designs for managing power quality and waveform data; (4) systems integration of monitoring data with other needed information systems (e.g., electrical data, operations, SCADA, outage management, customer information, work management, asset management, etc.); and (5) state-of-the-art fault location, prediction, and analysis. The deliverable for this task will be a report on the state-of-the-art technologies in the areas listed above along with recommended priorities for development and implementation in the project.	DOE Funding Opportunity Number DE-PS02-05CH11270, Topic Area 3, "Development and Demonstration of Advanced Monitoring Systems for Fault Location, Analysis, and Prediction."
GE-ENMAC System	Available now	This system allows control room operators to view real-time measurements on the network, and perform remote telecontrol operations combined with front-end data processing. The ENMAC system integrates customer outages with up-to-date status of the distribution network, providing accurate information to customers concerning the status of power interruptions.	http://www.gepower.com/prod_serv/products/scada_software/en/enmac.htm
Areva - BiTRONICS 70 Series Real-Time Monitoring and Event Recording	Available now	The BiTRONICS 70 Series Measurement System is a substation automation solution designed to satisfy the real-time monitoring and event recording needs of AC network operators. The BiTRONICS 70 Series Measurement System consists of four component types: monitoring and recording IEDs, detached displays, firmware, and software. These components form a real-time monitoring and event recording system for use in high voltage AC substations.	http://www.areva-td.com/solutions/liblocal/docs/1097584056077-70s_en_1413.pdf
AREVA-CBWatch	Available now	The CBWatch-2 continuously monitors circuit breaker condition and signals any malfunction to maintenance services in real time. The CBWatch-2 reduces maintenance cost and failure risk.	http://www.areva-td.com/solutions/US_402_CBWatch+-+2+Modular+Circuit+Breaker+Monitoring+System.html
Dynamic Security Assessment	Available now	On-line technology that takes a snapshot of the system condition, performs comprehensive security assessments in near real time, and provides operators with warnings of abnormal situations, as well as remedial measure recommendations.	Lei Wang and Kip Morison, "Implementation of Online Security Assessment", *IEEE Power and Energy Magazine*, September/October, 2006
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P)	Available now	The Grid-3P provides state-of-the-art performance monitoring technology for managing today's electric grid. It measures frequency, voltage, congestion, and market power. The Grid-3P saves data on abnormal operating patterns and predicts system response in near real time.	http://www.electricpowergroup.com/epg_grid3p.html
HIQgrid Digital Control System	Available now	The HIQgrid Digital Control System is a flexible monitoring and control system that can be adapted to any energized equipment. It connects devices from different systems (e.g., distribution transformers, streetlights, etc.) to a common control interface. The system is scalable up to hundreds of thousands of control points.	http://www.power-one.com/powergrid-controls/

Advanced Control Methods			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Distribution Fast Simulation and Modeling D-FSM	> 3 Years	The D-FSM project helps operators to control and optimize the grid in a safe, reliable, and efficient way.	http://www.epri.com/IntelliGrid/FSM.html
CERTS Monitoring Applications Based on Synchronized Phasor Measurements	In demonstration test	The major processes for the utilization of synchronized phase measurements are data acquisition, post disturbance analysis, results analysis, model validation, remediation planning, and RAS threshold validation. All of these processes require an underlying communication network such as the Internet.	http://certs.lbl.gov/pdf/synphasor-appguide.pdf
GRIDSTAT	> 3 Years	GRIDSTAT is a flexible power grid communication architecture that provides a common service platform for disseminating power grid status information within and between power utilities, energy brokers, end-users, and other participants. It allows input devices (publishers) to post or publish status information that will be available to grid monitors.	http://www.gridstat.net/; Microsoft Public Sector, Washington State University / PNNL; David E. Bakken, bakken@eecs.wsu.edu
Wide Area Measurement System (WAMS)	In service in the West	WAMS continuously monitors power grid performance and provides operators with high-quality data and analysis tools. Bonneville Power Administration, electric utilities, and industry have collaborated to develop and implement this system across the Western power grid. It detects imminent grid emergencies, mitigates grid outages, improves analysis and control, and enables dynamics analysis and modeling.	http://www.naspi.org
The Grid Friendly Appliance™ Controller	Ready for licensing	The Grid Friendly Appliance controller developed at PNNL senses grid conditions by monitoring the frequency of the system and provides automatic demand response when needed. Within each of three vast interconnected areas of the North American power grid (East, West, and Texas), a disturbance of the 60-Hz frequency is a universal indicator of serious imbalance between supply and demand that, if unarrested, could lead to a blackout. This simple computer chip can be installed in household appliances, turning them off for a few minutes or even a few seconds to allow the grid to stabilize. The controllers can be programmed to autonomously react in fractions of a second when a disturbance is detected, whereas power plants take minutes to come up to speed. They can also be programmed to delay restart after a power outage instead of all coming on at once, thus easing power restoration.	http://gridwise.pnl.gov/technologies/transactive_controls.stm
Petri Net Analysis Applied to the Electric Systems	> 3 Years	PNNL scientists have been developing an advanced network analysis technique called Petri nets to help analyze the combined engineering and market aspects of the grid. The nets capture the underlying mathematics of the coupled models in a way that will provide insights into how the complexity of the system may be managed with existing computational machinery. Because the network connectivity and influences are largely pre-computed, the nets have the potential to allow exploration of both local and global control opportunities and control systems' effects on the stability of the coupled systems in near real time.	http://gridwise.pnl.gov/technologies/modeling_theory.stm

Advanced Control Methods			
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Simulating the Combined Market and Physical Operations of Our Electric Power System	> 3 Years	The vision for the simulation framework is to create an open source environment where independently developed software components can be shared by other people and organizations, and a variety of simulation environments can be configured to address analysis needs. This unique set of simulation tools will span energy systems currently analyzed in isolation—the transmission grid, distribution systems, and customer systems (equipment and appliances)—and link their physical performance and control with the economic markets that will drive them in the future. Today's tools evaluate specific aspects of the system; however, since they are not interconnected, it is very difficult to model the interactions between different systems. Yet, this very capability is required to understand the effect of GridWise solutions on our energy systems.	http://gridwise.pnl.gov/technologies/simulations.stm
DSOM® (Decision Support for Operations and Maintenance)	Available through PNNL	DSOM® is a patent-pending expert operations and maintenance system that integrates plant operations, fuel management, and maintenance processes. DSOM is built around the concept of condition-based management. DSOM software collects and verifies operations data, analyzes them in a customized facility database, and lets operators know, in real time, if a system is malfunctioning or running below expectations. Beyond seeking early warning signs of problems, DSOM identifies potential problematic conditions, determines their root cause, and prioritizes recommended solutions.	http://www.pnl.gov/dsom/
Enhanced Automation (EA)	Available now	EA adds weather, electricity prices, and meter data to an energy management system to better control building costs, comfort, and health.	http://www.energy.ca.gov/enhancedautomation/index.html
Distribution Asset Analysis (DAA) Suite™	Available now	By reconciling hourly SCADA data at the substation level with end-use customer and other sources of data, DAA Suite™ provides an engineering basis for predicting transformer loading and actual system-wide asset loads.	http://www.itron.com/pages/products_detail.asp?id=itr_000372.xml
Smart Maintenance	Available now	Smart maintenance is preventive maintenance, work orders, inventory, predictive maintenance, and maintenance requests, all in one package.	http://www.smartwaregroup.com/landing.asp?code=google&kW=m-s
Center for Computational Learning Systems (CCLS)	Available now	CCLS has developed software that prioritizes system maintenance, providing real-time assessments of failure susceptibility; real-time control; lean management of operations; and future grid design simulation, testing, and validation. It also provides software for analysis, design, operation, and control of electrical power systems and critical infrastructures that have interdependencies with electrical power systems. CCLS is working closely with Con Edison and EDD, Inc.- VT to modernize grid functionality in New York City.	Columbia University, David Waltz, waltz@ccls.columbia.edu
Advanced Feeder Automation	Available now	Advanced Feeder Automation is an automatic power restoration system that uses distributed intelligence and peer-to-peer communication to switch and isolate a faulted line section and restore power to the unfaulted line sections.	Vendor Websites (S&C, ABB, GEPower, etc.)

Advanced Control Methods			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Automatic Protective Coordination After Feeder Reconfiguration	Available now	Protection coordination is automatically updated as circuits are reconfigured. The Precision Curve Fitting algorithm automatically develops a protective curve that coordinates tightly with the substation breaker. By using a SpeedNet Radio system to distribute information at high speed, time-current coordination settings of downstream IntelliRupters can be set automatically. The Automatic Protection Setup maximizes the number of IntelliRupters with unique time-current coordination settings, and the Communication-Enhanced Coordination ensures that only the last device feeding a faulted section clears the fault. This protection system allows deploying an unlimited number of IntelliRupters for circuit segmentation.	http://www.sandc.com/products/intelliteam/it2_demo.asp#
Transient Stability	Available now	Real-time phasor measurements and improved communication make it possible to determine whether a transient swing in the power systems is stable or unstable.	"Real-Time Stability in Power Systems" Edited by Savu C. Savulescu; http://ieeexplore.ieee.org/xpls/absprintf.jsp?arnumber=1610668
Real-Time Voltage Stability	1–3 Years	The onset of a voltage collapse point is calculated based on load characteristics and PMU measurements. If the stability margin is small and the reactive power reserves are nearly exhausted, then controls are deployed to steer the power system away from the critical point.	"Real-time Stability in Power Systems" Edited by Savu C. Savulescu; http://ieeexplore.ieee.org/xpls/absprintf.jsp?arnumber=1610668
Fault Locator for Distribution Systems	2–5 Years	Fault location using traveling waves has been applied in extra-high voltage power grids successfully. Due to its complications and high cost, this technique has not been easily accepted for use in distribution systems. A new traveling-wave fault location system is being developed in a cost-effective manner for power networks (particularly the distribution system). Two traveling wave sensors capture the current traveling wave that flows from the capacitive equipment to ground, and the voltage traveling waves during all 3 phases.	Google Search http://www.google.com/search
Physical Operating Margin (POM) for Ultrafast Load Flows with Boundary of Operating Region Visualization Tools	Available now	This technology performs ultrafast load flows (a 40,000 bus system solved in 0.5 seconds) and generates nomograms for operators that show regions of secure operations limited by voltage constraints, voltage instability, thermal limits, and flow gate constraints.	V&R Energy Systems Research, Inc.
Physical Operating Margin (POM) for Ultrafast Load Flows with Optimal Mitigation Measures (OPM)	Available now	Optimal mitigation measures can be applied on-line to expand the boundary of the operating region defined by POM technologies, allowing for reduced transmission congestion, optimal outage management, and optimal CAPEX planning.	V&R Energy Systems Research, Inc.

Advanced Control Methods			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Physical Operating Margin for Transient Stability Analysis (POM/TS) Accelerated with Fast Fault Screening (FFS) Algorithms with Optimal Mitigation Measures (OPM)	1–2 Years (in demonstration)	When integrated with OPM this technology can support CAPEX planning for minimal cost mitigation of transient instabilities. In operations it can mitigate potential transient instabilities.	V&R Energy Systems Research, Inc.
IntelliTeam - S&C Electric	Available now	This technology provides automatic restoration to the unfaulted section of the grid (without overloading components) using multi-agents to control protective devices and provide a reconfigured grid with fully coordinated protection.	S&C Electric; http://www.sandc.com
ROAMS System - Columbia University	Available now	This technology serves as a machine-learning ranking engine whose aim is to produce a real-time list of the network's feeders sorted from most to least susceptible to failure. It is being applied on the ConEd system in collaboration with Virginia Tech.	Columbia University, Dave Waltz, waltz@ccls.columbia.edu
Distributed Energy Workstation (DEW)	Available now	DEW creates integrated transmission-distribution system models that create models of each individual customer supplied by the grid.	Electrical Distribution Design (EDD), Virginia Tech, Robert Broadwater, dew@vt.edu
SensorBridge™	Available now	SensorBridge™ is a sensor-system middleware product that enables rapid integration of sensor and actuator assets into existing data systems, including monitoring and control systems, and streamlined development of new sensor systems. Augusta Systems's products support intelligent, sensor data filtering, processing, and communications on sensor processing systems at stations and substations, or among other grid equipment components.	Augusta Systems, Inc; http://www.augustasystems.com
Self Improving Software Algorithms	> 1 Year	Self-improving software learns from unfamiliar data and then adjusts itself to better handle the data. The key is that the algorithms learn from how the pieces of data fit within the range of possibilities, rather than having to learn the data's details.	Columbia University, Dave Waltz, waltz@ccls.columbia.edu
Advanced Grid Observation Reliable Algorithms (AGORA)	Available now	AGORA validates the quality of real-time data and off-line system models. It graphically monitors and analyzes the state of the electric grid and performs contingency analysis, clearance, and outage requests. AGORA investigates, evaluates, and predicts how the system will respond if critical equipment is forced out of service. It automatically generates and proposes optimized plans for system restoration when presented with a large real-time or simulated system disturbance.	http://www.elequant.com/products/agora/
Weather and Load Forecasting - Artificial Neural Network (ANN)	Available now	ANN is an interconnected group of artificial neurons that uses a mathematical or computational model for information processing based on a connectionist approach to computation.	Columbia University, Dave Waltz, waltz@ccls.columbia.edu

Advanced Control Methods			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Weather and Load Forecasting - Fuzzy Logic	Available now	Fuzzy logic is derived from the fuzzy set theory in which reasoning is approximately rather than precisely deduced from classical predicate logic.	http://web.cs.bgsu.edu/maner/wxsys/wxsys.htm
Weather and Load Forecasting - Numerical Weather Prediction (NWP)	Available now	Numerical weather prediction models are computer simulations of the atmosphere. The models use analysis as the starting point and evolve the state of the atmosphere forward in time, using an understanding of physics and fluid dynamics.	Vasquez, T, *Weather Forecasting Handbook* (5th Edition), , 2002
Weather and Load Forecasting - Ensemble Forecasting	Available now	Ensemble forecasting uses numerous forecasts to reflect the uncertainty in the initial state of the atmosphere (due to errors in the observations and insufficient sampling). The uncertainty in the forecast can then be assessed by the range of different forecasts produced. Ensemble forecasting can better detect the possibility of extreme events at long range.	http://www.cdc.noaa.gov/map/images/ens/ens.html
Weather and Load Forecasting - Nowcasting	> 1 Year	Forecasting weather in the 0–6 hour timeframe is often referred to as "nowcasting." In this range the human forecaster still has an advantage over computer NWP models.	http://www.rap.ucar.edu/projects/wsddm/bams.pdf
Integration with Other Enterprise-Wide Processes and Technologies Using Web Services	Available now	The term "Web Services" describes a standardized way of integrating web-based applications using the Extensible Markup Language (XML); Simple Object Access Protocol (SOAP); Web Services Description Language (WSDL); and Universal Description, Discovery, and Integration (UDDI) open standards over an Internet protocol backbone.	http://www.w3.org/TR/ws-arch/
Integration with Other Enterprise-Wide Processes and Technologies Using Grid Computing	> 1 Year	Grid computing is an emerging computing model. It provides the ability to perform higher throughput computing by taking advantage of multiple networked computers to model a virtual computer architecture that can distribute process execution across a parallel infrastructure.	http://www.gridforum.org/
Integration with Other Enterprise-Wide Processes and Technologies	> 3 Years	The Semantic Web is a project to create a universal medium for data, information, and knowledge exchange by giving semantics to document content on the World Wide Web.	http://www.w3.org/2001/sw/Activity
Integration with Other Enterprise-Wide Processes and Technologies	> 1 Year	New, real-time operating information will be efficiently integrated for use by the smart grid with existing asset management and customer service processes and technologies. This integration is expected to dramatically increase the effectiveness and efficiency of enterprise-wide programs.	http://www.sisconet.com/downloads/KnowUtil.pdf; http://uaelp.pennnet.com/Articles/Article_Display.cfm?Section=Articles&ARTICLE_ID=243625&VERSION_NUM=4&p=22

Advanced Control Methods			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Cleveland State Center for Research and Aerospace Technology	5 Years +	The underlying technology involves advancements in the fields of instruments, controls, and electronics. The advancements include the following: (1.) design a distributed, fault–tolerant, modular power system; (2) develop the dynamics and control of active magnetic bearings for flywheel energy storage without using conventional sensors; and(3) deliver power through wireless systems (power beaming).	http://www.csuohio.edu/engineering/create/
Montana Tech Load Control System Reliability	3–5 Years	Research will focus on two areas: (1) real-time load control methodologies, and (2) measurement-based stability-assessment operation and control tools. Orientation is toward transmission applications. The proposed technology research, development, and demonstration project is aimed at applying advancements in intelligent control and information technologies to the challenges of improved reliability of existing grid resources, load leveling of limited energy resources, and improved efficiency among load systems on a common grid.	http://www.mtech.edu/research/
WVU Integrated Controls (APERC)	3–5 Years	The initial focus will be on developing, testing, and validating the performance of a multi-agent system for controlling technical performance of a distribution feeder. The objective is to achieve robust, reliable multi-agent systems capable of maintaining and improving circuit stability through reduced fault vulnerability, fault tolerance and isolation, and rapid self-healing/correction of disturbances.	http://www.aperc.wvu.edu; West Virginia University, APERC, Ali Feliachi, alfeliachi@mail.wvu.edu
NETL Pilot Energy Cost Evaluation (Prologic)	Available now	This demonstration/service project is designed to support several NETL buildings at the Morgantown, WV, campus and will evaluate the cost savings associated with using existing commercial off-the-shelf technology. The system will be installed to control indoor and outdoor lighting, and HVAC parameters for research laboratories, computer centers, and other vital facilities at the NETL campus.	http://www.profile-systems.com/ (P1800 system)
Grid Shock Absorber	3–5 Years	This concept is the reconfiguration of existing large interregional networks into sets of asynchronously operated sectors connected exclusively by links based on new DC technologies. Such DC-aided segmentation should minimize and possibly eliminate system stability issues, and improve the control of power flow among sectors under both normal and emergency conditions.	EPRI Journal - Spring 2007, Aty Edris (aedris@epri.com)
eBoard	Available now	The eBoard Power Distribution System is an innovative new technology that allows power to be freely transmitted to any part of a room or building. With eBoard the problem of electrical wiring and the location and number of outlets is solved. This system has three major parts: adapter, track, and power hub. The power hub is the control component of the eBoard system. This power hub can control energy usage and provide safety from dangerous spikes. Some advanced power hubs are especially useful for renewable energy as they can maintain a constant stream of energy.	http://symbioticpower.com/system/system.htm

Table 3: Advanced Control Methods

SENSING AND MEASUREMENT

Table 4: Sensing and Measurement

Sensing and Measurement			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Wireless, Intelligent System Sensors for Condition Information	> 5 Years	An ad-hoc (or "spontaneous") network is a local area network or other small network—especially one with wireless or temporary plug-in connections—in which some of the network devices are part of the network only for the duration of a communications session or, in the case of mobile or portable devices, while in close proximity to the rest of the network. This ad hoc network allows for integration of a computer-enabled mobile workforce with field assets using a GPS location stored in a geographic information system (GIS). The Gridsense LineTracker system is available to keep track of distribution line topology changes, fault location, and load monitoring.	http://w3.antd.nist.gov/wctg/manet/adhoclinks.html; http://www.ember.com/; http://www.gridsense.net
Wireless, Intelligent System Sensors for Condition Information	Available now	Low-cost wireless nodes that operate as intelligent radio devices (IRD) in a mesh network at 2.4 GHz to 5.2 GHz with ranges up to 10 miles are available and can be added to various substation sensors (e.g.,T, I2T, P, etc.) and lines (e.g.,T, strain, stress, etc.). This IRD mesh can also be used with wireless nodes on towers in a mesh network for reliability for broadband communication. (Other 802.11g wireless Ethernet suppliers include MDS, Tropos, Vyvo, RadioLinx, and Cirronet.)	Intelicis, MDS, Vyvo, RadioNet, Cirronet
Wireless, Intelligent System Sensors for Condition Information	Available now	Low-cost wireless nodes that operate as IRDs in a mesh network on cellular systems based on 2G or 3G GSM or CDMA technologies at 0.8 GHZ to 1.9 GHz are available and can be added to various substation sensors (e.g.,T, I2T, P, etc.) and lines (e.g.,T, strain, stress, etc.). Suppliers of fielded cellular interface devices that include both serial and Ethernet type interfaces include I.P.S. Group, eLutions, and Telemetric.	http://www.elutions.biz/; http://telemetric.com/
Wireless, Intelligent System Sensors for Operating Information (MW, MVAR, Volts, Amps, PF, PQ, etc.)	> 5 Years	Another approach to low-cost wireless nodes uses short-range backscatter technology that harvests power to operate sensors (e.g., T, I2T, P, T, strain, stress, etc.). Line sensing can employ helicopter data collection.	TVA
Wireless, Intelligent System Sensors for Operating Information (MW, MVAR, Volts, Amps, PF, PQ, etc.)	Available now	I-Grid is a national web-based power disturbance monitoring and reporting system that is both innovative and groundbreaking. Developed by SoftSwitching Technologies and with close to 1500 monitors installed nationwide, I-Grid can provide analysis of events in almost any given region. (Website is www.i-grid.com)	http://www.softswitch.com/sst/igrid.do

Sensing and Measurement			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Advanced Instrument Transformers	Available now	Fiberoptic potential transformer (PT) and current transformer (CT) sensors and meters are available from NxtPhase (fiberoptic cables) and ABB (silicon crystals) and accurately measure voltage and current to revenue standards at any voltage over the entire range of the device. JDSU Photonic Power offers an optically powered CT sensor with up to 500 MW delivered to the sensor head over a multiplexed fiber optic link. Other vendors include Mitsubishi Electric and Hitachi/Toshiba.	http://www.nxtphase.com/; http://www.abb.com/; http://www.jdsu.com//; http://www.mitsubishi.com/; http://hitachi.com/; http://www.airak.com
Advanced Instrument Transformers	> 5 Years	The measurement system is composed of a current sensor and the associated electronics module. The current sensor includes an emitter, transmission structure, and receiver. The magnetostrictive material of the emitter generates elastic (mechanical) waves under the alternate magnetic field induced by the primary current to be measured. The 50 Hz or 60 Hz electrical signals are then converted into elastic waves that propagate through a dielectric coupling structure until they reach the receiver where the elastic waves are converted back into electrical signals.	http://ieeexplore.ieee.org/Xplore/login.jsp?url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F9986%2F32066%2F01492231.pdf%3Farnumber%3D1492231&authDecision=-203
DONUT	Available now	DONUT is an advanced instrument platform designed for real-time acquisition and data logging on high-voltage overhead transmission systems.	Underground Systems, Inc.; http://www.usi-power.com
Wide Area Protection	Available now	Real-time phasor measurements and improved communication make it possible to determine whether a transient swing in the power system is stable or unstable.	"Real-time Stability in Power Systems" Edited by Savu C. Savulescu; http://ieeexplore.ieee.org/xpls/absprintf.jsp?arnumber=1610668
Wide Area Protection	2–5 Years	The voltage collapse point is calculated based on the load characteristics and PMU measurements. If the stability margin is small and the reactive power reserves nearly exhausted, controls are deployed to steer the power system away from the critical point.	"Real-time Stability in Power Systems" Edited by Savu C. Savulescu; http://ieeexplore.ieee.org/xpls/absprintf.jsp?arnumber=1610668
Wide Area Measurement System (WAMS)	2–5 Years	WAMS uses synchronized phasor measurements that can stream data, in real time, to phasor data concentrator (PDC) units. PMU networks have been deployed at several utilities. The primary impediments are cost, reliability, and assuring value for the investment.	http://phasors.pnl.gov/
Radio Frequency Identification (RFID)	2–5 Years	RFID is a technology similar in theory to bar code identification. With RFID, the electromagnetic or electrostatic coupling in the RF portion of the electromagnetic spectrum is used to transmit signals. It could also be used with a GIS system with pre-determined GPS position of electrical asset.	http://www.xbow.com/; http://www.rfidnews.org/
Fiber Optic Sensors	Available now	This new signal conditioner, designed for direct and real-time measurement of hot spot monitoring for small and medium transformers, is intended for utilities with concerns about the safety and reliable operation of their high voltage equipment. The Nortech TT represents a significant development and cost reduction effort to meet the electric industry's ever-growing requirements in terms of monitoring.	http://www.fiso.com; http://www.luxtron.com/

Sensing and Measurement			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Electromagnetic (EM) Sensors	Available now	EM sensing technology—ultra-low noise, low-frequency electromagnetic sensing systems and services—has been used for applications such as lightning detection, electrostatic hazard monitoring, and underground facility detection. QUASAR Federal Systems, Inc. (QFS) is at the forefront of new areas such as airborne and underwater electric and magnetic field sensing.	QUASAR Federal Systems (QFS), Inc.; http://www.quasarusa.com
Dynamic Ratings (Lines, Components)	2–5 Years	Dynflo distributed series impedance devices on each phase on each tower; these devices can also measure line temperature and line sag. Dynamic ratings of transformers are being demonstrated at EKPC now.	Dr. Deepak Divan, Georgia Tech's Intelligent Power, Infrastructure Consortium (IPIC), http://www.ipic.gatech.edu/
Dynamic Ratings (Lines, Components)	2–5 Years	An alternative to a video-based "sagometer" is to use a differential GPS to directly measure sag. Differential GPS has been demonstrated to be accurate for use in measuring distances within less than half a meter. A PowerDonut load cell measurement of sag has been developed and tested as part of a demonstration program at the Power Systems Engineering Research Center (PSERC).	http://certs.lbl.gov/pdf/52047.pdf; http://www.pserc.org
Dynamic Ratings (Lines, Components)	2–5 Years	PSERC sponsored the development of the visual basic software program called Grandline that calculates line sag and current-carrying capacity in real time. The software uses inputs from (1) direct and indirect measurements of wind and local temperature variables and (2) GPS line sag or implied line sag from calculations.	http://www.pserc.org
Dynamic Ratings (Lines, Components)	2–3 Years	GATECH's IPIC plans to develop a wireless Sensornet for the dynamic thermal rating of a line at a target cost of $200 per sensor. This device would allow the sensing of thermal line rating for all spans, which would eliminate the need to identify a critical span and the effects of micrometeorological effects such as different local wind conditions.	Dr. Deepak Divan, Georgia Tech's Intelligent Power, Infrastructure Consortium (IPIC), http://www.ipic.gatech.edu/
Transformer Monitoring Systems	Available now	Sophisticated monitoring tools that combine several different temperature and current measurements to dynamically determine temperature hot spots in transformers are now commercially available.	Vendor Websites
Transformer Monitoring Systems	Available now	Sophisticated transformer monitoring tools that measure dissolved gases in oil and predict the health of transformers and load tap changers (LTCs) in real time are now commercially available. They can be used to generate green-yellow-red condition for operators. The latest generation from Serveron extends previous EPRI work to develop a low-cost solid-state gas-in-oil monitor. Extraction of a gas sample from oil is used in a commercially available field-reliable gas chromatograph to give precise gas concentration measurements without timely and costly oil sampling/lab analysis currently in use by utilities.	http://www.serveron.com
Circuit Breaker (CB) Monitoring Systems	Available now	CB real-time monitoring systems measure (1) the number of operations since the last maintenance, (2) operate times, (3) oil or gas insulation levels, (4) I2t energy, and (5) breaker mechanism signatures. Monitors are available from several sources including GE TM1800, ABB, and Siemens.	http://www.ge.com; http://www.abb.com/; http://siemens.com/index.jsp

Sensing and Measurement			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Cable Monitoring Systems	Available now	Cable monitors help to determine changes in buried cable health by trending partial discharges or periodic impulse testing of monitored lines. Monitors include GE IDA 200, AVO CableTrend® and NetworkTrend®, KEMA, and others.	http://www.ge.com; http://www.avobiddle.com/Products.htm; http://www.kema.com/
Battery Monitoring Systems	Available now	Batteries are used in substations and generation plants as auxiliary power when grid power is unavailable. Batteries are a high-maintenance item and advances in low-cost monitoring help to minimize battery failures. Monitors can now check cell health, specific gravity, liquid level, cell voltage, and charge/discharge characteristics. Vendors include Alber, Trimetric, Liebert, Xantrex, VictorEnergy, and others.	http://alber.com/; http://liebert.com/; http://trimetric.com/; http://www.xantrex.com/; http://www.victronenergy.com/
I-Sense® Power Quality Monitor, I-Grid® Monitor System	Available now	These power quality monitoring devices can be used as part of a nationwide electric power monitoring system.	SoftSwitching Technologies Corp.; http://www.softswitch.com
AEP Ultra-sonic Transformer Monitor	>2 Years	This sensor and analysis software can detect the high-frequency electrical and audio noise associated with incipient arcing. The R&D effort is intended to ascertain the patterns and signatures associated with high-energy versus low-energy events and signatures associated with a component problem.	SoftSwitching Technologies Corp.; http://www.softswitch.com
Advanced Metering Infrastructure (AMI)	Available now	AMI is a complete system that integrates advanced meters with an appropriate communication system to provide consumer consumption information and system status to energy providers. Advanced meters and the supporting infrastructure are available from a number of vendors including: AMDS, Amron, Badger Meter, Cannon Technologies, Cellnet, Comverge, DCSI, Elster, eMeter, ETG, GE, Hexagram, Hunt Technologies, Itron, Landys-Gyr, Nertec, Sensus Metering Systems, Silver Springs Networks, Smartsynch, Tantalus Systems, Telenectis, and Transdata.	Vendor Websites
Consumer Portal	Available now	A Gridpoint Protect portal (the size of a small file cabinet) connects to the circuit breaker panel and works in conjunction with dynamic pricing to manage energy consumption. In addition, the unit also stores electricity using gel-style batteries.	http://www.gridpoint.com
Consumer Portal	Available now	A consumer portal is a smart interface between the consumer and the energy provider. It will provide emerging information-based solutions that improve the efficiency, comfort, and safety of businesses, buildings, and homes and will integrate with power delivery system applications.	http://www.broadbandenergynetworks.com/; http://www.mentorgen.com/index.php?option=com_content&task=view&id=57&Itemid=74
Consumer Portal	2–3 Years	Based on an open flexible architecture, the portal will facilitate the implementation of new services such as DR and real-time pricing, outage detection, remote connect/disconnect, support to distribution operations, PQ monitoring, and improved customer information.	http://www.epri-intelligrid.com/intelligrid/docs/1012028_Consumer_Portal_7.05.pdf

Sensing and Measurement			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Consumer Portal	Zigbee: Available now. Z-Wave: Available in 2–3 years	GoodWatt, a device from Invensys, has been demonstrated by BPA in their non-wires solution program at demand response implementations in Salem and Ashland, OR, on hundreds of customer sites. The customer monitors real-time energy usage and determines a control strategy in response to a critical peak price signal from BPA. GoodWatt acts as a gateway from the customer's utility meter to other controllable loads such as pool pumps, water heaters, and air conditioners. The portal uses the emerging industry RF standard Zigbee with chipsets from Cirronet. Other emerging solutions may be based upon an Intel-backed RF home network solution called Z-Wave with chipsets from Zen-sys.	http://cirronet.com/zigbee.htm; http://zigbee.org/; http://www.z-wavealliance.org/modules/start/; http://www.zen-sys.com/
Consumer Portal	Available now	During times of economic or reliability stress on the power grid, utilities and grid operators need a quick, simple, and convenient way to alert customers. PG&E, as part of both its demand bidding and critical peak pricing programs, has deployed the Energy Orb from Ambient Devices, which is placed in the customer's lobby or on the facility manager's desk. A low-powered device (3.5W), the orb changes colors from blue to yellow to red depending upon the level of the system alert. Communication to the device is via a radio signal dispatched by either the utility or grid operator.	http://www.pge.com/
eMiner™	Available now	This technology acts as an interface for customer meters, building and process control systems, and live market information. It can potentially serve as an energy management tool for load response, which requires secure, reliable communications among meters, substation systems, generating assets, distributed generators, grid status and market prices databases, and end-user building/process control systems. The technology has been implemented at 100 sites including commercial, industrial, substation, and generating asset applications.	WPS Resources Corporation – Applied Technology Group
Wireless ePulse	Available now	This technology provides data recording and communication for early detection and notification of failures. MTS Technologies' primary customer is the U.S. military; however, MTS has also been involved in integration, diagnostics, security, and simulation technologies to enhance the electric grid.	MTS Technologies, Inc.; http://www.mtstech.com
Advanced Protection Systems	Available now	Advanced Protection Systems are intelligent electronic devices that sense power system operating conditions and perform calculations and analysis to determine the risk to assets and the grid. The systems also initiate high-speed control actions to protect the assets and the system from damage, instability, and propagating outages, and provide near-instantaneous information to system operators via a local data acquisition device—either wirelessly, optically, or via cable. Examples include Schweitzer-type protective relaying devices, distribution automation, and substation automation schemes, etc.	http://www.selinc.com/; http://www.basler.com/h tml/pcs700v.htm

Sensing and Measurement			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Advanced Protective Relays	Available now	All current suppliers of advanced relays offer a complete line of technologies for the protection, monitoring, control, automation, and metering of electric power systems. Industry adoption of standard protocols has advanced to support both DNP3 and IEC 61850. Rapid adoptions of IEC standards by international utilities have accelerated. Advanced functions include integrated fault location, hi-z distribution fault detection, advanced transformer and bus-fault-detection algorithms, and use of network communication for advanced relaying.	http://selinc.com/; http://www.ge.com/en/; http://www.abb.com/; http://www.zivpmasc.com/; http://www.siemens.com; http://areva.com; http://beckwithelectric.com/
Advanced Overhead Line Protection	Available now	To test for faults, PulseClosing applies a very fast, low-energy pulse to the line, significantly reducing damaging fault currents and voltage sags on the faulted line as well as adjacent feeders. Substation transformers will experience fewer through-faults, extending their life. Cables, overhead conductors, splices, and terminations will experience less thermal and mechanical stress from through-fault currents.	http://www.sandc.com
Waveform Analysis	2–5 Years: integration of FLIR with Outage Management and RF AMI systems	Fault location using traveling waves has been applied in extra-high-voltage power grids successfully. Due to its complications and high cost, it is still difficult for this technique to be accepted for use in distribution systems. A new traveling-wave fault-location system is being developed in a cost-effective way for power networks (especially for distribution system). Traveling-wave sensors capture both the current traveling wave flowing from the capacitive equipment to ground and the voltage traveling waves during all three phases. Advances in fault location now allow utilities to reduce customer outage by quickly locating a fault, identifying its location, dispatching available trouble crews, and tracking the activity in an outage management system. The location of the fault can be independently verified by integration of data from an AMI meter reading system.	http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=1348815
Special Protection Systems	Available now	Special Protection Systems, also known as remedial action schemes, allow grid operators to implement power transfers across the grid that, under normal criteria, would not comply with N-1 or N-2 contingencies. Grid operators can load transmission lines closer to thermal limits beyond normally prudent voltage or system stability limits. The systems consist of real-time monitoring of key generation assets or transmission lines and the associated power flows. Upon change of status (loss of generation and/or loss of transmission line), a pre-programmed set of actions is performed (e.g., wide area load shed, generator re-dispatch, separation of interties, islanding). Each regional reliability organization sets rules for design and implementation along with the North American Electric Reliability Corporation (NERC) compliance and the IEEE Power Engineering Society PSRC standards body. Special Protection Systems and Remedial Action Schemes are in place today especially in the Western Interconnection. Advanced use of SONET/VLAN/Ethernet communication schemes has been piloted.	http://www.wecc.biz/documents/2006/General/RAS_Guide_6-10_clean.pdf; http://www.nerc.com/docs/standards/sar/PRC-005-008-011-017_Report_Approved_by_PC.pdf; http://www.pes-psrc.org/; http://www.pes-psrc.org/Reports/Voltage%20Collapse%20Mitigation.pdf; http://www.pes-psrc.org/Reports/; http://www.spectrum.ieee.org/print/2407

Sensing and Measurement			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Electric Grid Monitoring (Genscape)	Available now	R&D is underway at the University of Louisville to develop low-cost, rapidly deployable, self-powering transmission line monitors that relay line operational status from remote locations wirelessly. Measurement and monitoring of power flow and direction that were originally designed for marketing purposes may be useful for government, Federal Energy Regulatory Commission, and Office of Electricity applications. Environmental power sources (e.g., acoustic, electromagnetic, radiofrequency, vibration) suitable for scavenging in the transmission line environment will be researched for monitor sensors, processors, or communication module operation.	Genscape Inc.; http://www.genscape.com
NXEGEN Connecticut Demand Response Technologies	Available now	NXEGEN Connecticut Demand Response Technologies demonstrate that real-time electricity metering, monitoring, and non-intrusive load management can benefit the commercial and/or industrial markets. Activities will include installation of real-time wireless metering and monitoring, and installation of automated and direct control systems.	http://www.nxegen.com/default.asp
Micro-Electro-Mechanical Systems (MEMS)	Available now	MEMS is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro fabrication technology. Microelectronic integrated circuits can be thought of as the "brains" of a system and MEMS augments this decision-making capability with "eyes" and "arms" to allow Microsystems to sense and control the environment. MEMS promises to revolutionize nearly every product category by bringing together silicon-based microelectronics with micromachining technology, making possible the realization of complete systems-on-a-chip. This technology is already being deployed in sensor manufacturing and chip-based accelerometer manufacturing.	http://www.memsnet.org/mems/what-is.html; http://www.sensorland.com/HowPage023.html; http://en.wikipedia.org/wiki/MEMS
Real Time Transmission Line Monitoring System (RL-TLMS)	Available now	RL-TLMS is a non-contact real-time sensor system for monitoring HV overhead transmission lines. Passive AC magnetic field sensors (located under the phase conductors) are used to accurately and reliably quantify the AC magnetic fields. System operations and accuracy are not affected by the environment. This system can be calibrated to report phase currents, conductor clearance, maximum conductor temperature, and instantaneous ampacity (maximum current-carrying capability).	www.prometheandevices.com
Laser Cameras	Available now	Compact laser cameras are used for measuring sag profile and conductor heights, and to manage vegetation in the vicinity of the transmission lines. Data communication to this device is available through the standard serial port or with the optional Bluetooth.	www.lasertech.com
Infrared (IR) Sensing	Available now	Infrared cameras convert thermal radiation emitted by different power system components to visual images that are calibrated to a temperature scale. This non-contact temperature data can be displayed on a monitor in real time and can be stored in digital storage for analysis. Some advanced IR cameras are already available in the market, which can achieve the accuracy of +/- 1% or +/- 1 °C. Recent technology enhancements in this field have helped to build the camera with built-in GPS, which recorded the location information every time readings were taken. The most advanced versions of these IR systems provide time-stamped 3-D thermal modeling of critical equipment and areas, plus intrusion monitoring with motion detection features.	http://www.flir.com/US/

Sensing and Measurement			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Partial Discharge Detection On-line with Localization (PDOL)	Available now	The PDOL methodology has been tested and developed by KEMA in Europe and is entering the pilot stage in the United States. The PDOL system is able to locate the origins of Partial Discharges from a complete MV cable connection by using only two inductive sensors, one at each cable termination. These sensors can often be installed while the cable remains in service. Data is measured continuously and measurement results are collected in a centralized control center, where the results are analyzed and interpreted. This on-line cable monitoring system can prevent various outages. This new on-line measuring technique (PDOL) has been tested on a 300-meter-long test cable circuit that grid managers installed on the grounds of the KEMA facility.	http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=IEECPS0020050CP5040v1-97000001&idtype=cvips&gifs=yes; http://tdworld.com/test_monitor_control/top_story/power-cable-permanent-monitoring/; http://www.fortnightly.com/pubs/10012006_TechnologyCorridor.pdf; http://www.kema.com/corporate/news/press_room/us_press_releases/Partial_Discharge_Detection_Online_with_Localization.asp

Table 4: Sensing and Measurement

IMPROVED INTERFACES AND DECISION SUPPORT

Table 5: Improved Interfaces and Decision Support

Improved Interfaces and Decision Support			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Advanced Pattern Recognition	> 1 Year	Pattern recognition is intrinsic to network intruder detection, forgery detection, biometrics, and next-generation computer interfaces. It is also intrinsic to automatic paraphrasing, translation, and language understanding.	http://www.trnmag.com/mtfpatternrecognition.html
Real-Time 3-D Visualization with Virtual Reality	> 1 Year	Real-time 3-D visualization with virtual reality supports power system simulation, analysis, and decision support.	http://www.pserc.wisc.edu/
Virtual Machines	> 1 Year	A virtual machine is a self-contained operating environment created by a software layer, which behaves as if it were a separate computer. Benefits of creating virtual machines include better exploitation of powerful computing resources and isolation of applications to prevent cross-corruption and improve security.	http://www.computerworld.com/softwaretopics/software/story/0,10801,110722,00.html?SKC=software-110722
Intelligent Alerting Systems	> 1 Year	Alerting systems deliver alerts on business performance, supply chain alerts, customer activity, monitored date, metered data, etc.	http://www.microstrategy.com
Intelligent User Interfaces (e.g., MIT's Project Oxygen)	> 1 Year	The use of techniques from the field of autonomous agents provides a new complementary style of human-computer interaction, where the computer becomes an intelligent, active, and personalized collaborator. Interface agents are computer programs that employ artificial intelligence methods to provide active assistance to a user of a particular computer application.	http://www.aaai.org/aitopics/html/interfaces.html; http://www.computerworld.com/softwaretopics/os/story/0,10801,73697,00.html
Region of Stability Existence (ROSE) Using PMU Data	1–2 Years (in demonstration)	ROSE data that directly input both SCADA data as well as phasor measurement data can be electronically plotted on a screen in the transmission dispatch center for an operator using phasor data in 2-D space. ROSE data also show regions of secure operations limited by voltage constraints, voltage instability, thermal limits, and flow gate constraints. Optimal mitigation measures can be applied on-line to expand the ROSE. The CEATI Power System Planning and Operations Interest Group is in negotiations with V&R Energy to demonstrate this software.	http://www.vrenergy.com/
On-line Transient Stability Monitor Using Fast Fault Screening	1–2 Years	A fast on-line transient stability monitor uses fast fault screening to determine the most severe faults. The monitor also uses an ultra-fast transient stability model by V&R Energy Systems Research (POM-TS). With fast fault screening and input from a state estimator model, POM-TS can solve transient stability limitations in under a minute. Eventually, when SCADA data is entered, transient instabilities will be monitored on line.	http://www.vrenergy.com/

Improved Interfaces and Decision Support			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
On-line Transmission Optimization Software	Available now	A fast on-line transmission dispatch optimization model already exists and is in use at ATC, ConEd, and Idaho Power. In Thailand, V&R Energy Systems Research is implementing a real-time transmission dispatch optimization software. The software has been shown to be much more robust than other existing applications. It can reduce transmission congestion by optimizing generator MW and MVAr dispatch, capacitor and reactor settings, transformer load tap change settings, phase shifter settings, and dynamic sources of reactive compensations. The software can also take non-affected lines out of service. It not only can reduce transmission congestion, but it is so fast that it can be used for optimum remedial action in the event of a contingency or an emergency.	http://www.vrenergy.com/
The Electricity Infrastructure Operations Center (EIOC)	Available now	The EIOC at Pacific Northwest National Laboratory brings together industry-leading software, real-time grid data, and advanced computation into a fully capable control room. EIOC allows researchers to work with real data-running scenarios to determine how to increase capacity and improve reliability models, and to test new technology without the cost and risk of disrupting the system.	http://eioc.pnl.gov/about.stm
Advanced Speech Recognition: Voice Activated Search Engine	> 1 Year	Speech recognition systems are composed of three major functions. First, words are captured and translated into a digital signal. Then a speech-recognition algorithm compares those signals to words and phrases from a pre-set dictionary. Finally, the software offers the most likely match for the spoken phrase. (Patent applied for.)	http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=/netahtml/search-adv.htm&r=1&p=1&f=G&l=50&d=ptxt&S1=7,027,987&OS=7,027,987&RS=7,027,987#top
Advanced Speech Recognition: Speech-to-Speech (S2S) Translation	> 1 Year	The goal of S2S Translation research is to enable real-time, interpersonal communication via natural spoken language for people who do not share a common language. The Multilingual Automatic Speech-to-Speech Translator (MASTOR) system is the first S2S system that allows for bidirectional (English-Mandarin) free-form speech input and output.	http://domino.watson.ibm.com/comm/research.nsf/pages/r.uit.innovation.html; DARPA and IBM Research
Haptic Interfaces for Control Inputs Through Hand Movements	> 1 Year	Haptic interfaces are devices that let users generate control input through hand movements and provide users with tactile and force feedback consistent with what the user is seeing. These systems permit users to sense and manipulate 3-D virtual objects with respect to features such as shape, weight, surface textures, and temperature. Haptic devices such as haptic gloves, joysticks, and tactile arrays have advanced rapidly and can generate a wide range of force and tactile feedback. These devices present the right tools for human-computer interaction researchers to develop haptic cueing and/or messaging systems and haptic spatial representation systems that integrate seamlessly with existing multimodal applications.	http://www.ieee.org/portal/site; Massachusetts Institute of Technology; Research in Progress (IEEE, DARPA, etc)

Improved Interfaces and Decision Support			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Integrated 3-D Video Cards into Visualization Programs	Available now	Today, AGEIA is dedicated to delivering dynamic interactive realism to the ever-demanding complexity of next-generation games. Its flagship solution, AGEIA PhysX, is the world's first dedicated physics engine and physics processor to bridge the gap between static virtual worlds and responsive unscripted physical reality. AGEIA PhysX allows developers to use active physics-based environments for a truly realistic entertainment experience. Technology is available today but not integrated within utility-scale visualization programs. The PhysX product used in the gaming industry has applications in combat training, robotics, etc.	http://www.ageia.com/about/index.html
Diffraction-Based Optical Crossbar Switch has Applications in Optical Networking, Holographic Video, and Optical Computation	> 1 Year	Actuality Systems' core product is the Perspecta platform, which consists of a unique 360-degree spatial display and the associated Perspecta software and software development kit. The platform enables users to render high-resolution spatial images that can be viewed from any angle as the user moves around the display. The display itself illuminates a record 100 million volume pixels, or "voxels," within a transparent sphere. Typical applications for the Perspecta platform include: drug discovery, such as visualization of protein structures; surgical and radiation treatment planning for doctors working to determine the exact location of a tumor on a CAT scan or mammogram; air-traffic control; game development; security specialists seeking a faster and more reliable way to visualize the contents of freight or passenger luggage; and numerous other possibilities. (Patent awarded.)	http://www.actuality-systems.com/site/content/pr_beam_steering.html
GIS Map Displays with Spatial Analysis, Attribute Mapping, and Data Conversion	Available now	GIS is a system for creating and managing spatial data and associated attributes.	http://www.esri.com/; http://www.fgdc.gov/nsdi/nsdi.html; http://www.gita.org/; Intergraph Corporation
GIS 3-D with Virtual Reality Simulation and Modeling and 3-D Visualization	> 1 Year	A new GIS 3-D system is being developed with the addition of virtual reality simulation and modeling.	http://www.esri.com/news/arcnews/summer04articles/virtual-reality.html
GIS 4-D Modeling with Time	> 1 Year	The GIS 4-D system generates a multi-dimensional presentation.	http://skagit.meas.ncsu.edu/~helena/gmslab/viz/vol1.html; http://www.geo.informatik.uni-bonn.de/publications/2002/ACM_GIS02_paper.pdf

Improved Interfaces and Decision Support			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Open GIS	2–5 Years	The vision of Open GIS® is a world in which everyone benefits from geographic information and services made available across any network, application, or platform. Approximately 80% of business and government information has some reference to location, but until recently, the power of geographic or spatial information and location has been underutilized as a vital resource for improving economic productivity, decision-making, and delivery of services. We are an increasingly distributed and mobile society. Technologies, services, and information resources must be able to leverage location, (i.e., my geographic position right now) and the spatial information that helps us visualize and analyze situations geographically. Products and services that comply with the Open Geospatial Consortium's open interface specifications enable users to freely exchange and apply spatial information, applications and services across networks, and different platforms and products.	http://www.opengeospatial.org/ Open Geospatial Organization
Origin GIS	Available now	By using a spatial network connectivity database and levering an industry-leading GIS mapping software, this tool provides the information needed to manage your distribution assets.	http://www.itron.com/pages/news_press_individual.asp?id=itr_002879.xml
GeoIQ™	Available now	This web-service application supports geospatial analysis and visualization. These applications are available for innovative heat-map visualization techniques that are well suited for use by non-technical personnel and decision makers.	http://www.fortiusone.com
GE Smallworld	Available now	Provides scalable, extensible, and open solutions that integrate with existing systems to leverage spatial data in new ways: throughout the enterprise and onto the Internet. It helps in understanding where customers are and the infrastructure through which products and services are delivered.	http://www.gepower.com/prod_serv/products/gis_software/en/index.htm
PowerWorld Retriever	Available now	Gives operators a real-time or historic view of the power system and its various parameters quickly, accurately, and in a format that increases situational awareness. Connects to external, real-time data sources to import and display real-time data.	http://powerworld.com/products/retriever.asp
CERTS VAR-Voltage Management Tool	Available now	The CERTS VAR-Voltage Management Tool substitutes a visual, bird's-eye view of the overall health of the grid for difficult-to-read tables of voltages at each monitoring point within the electricity system. By mining, analyzing, and presenting operational data in an easy-to-understand visual format, this tool addresses a key problem facing operators today—data overload—and enables them to effectively and reliably maintain safe operating margins.	http://certs.lbl.gov/pdf/rt-var-summary.pdf
Genscape Power North America	Available now	This is a web-based interactive map representing estimated, real-time power production and transmission flows for facilities monitored in the Continental United States.	http://www.genscape.com/na/index.shtml

Improved Interfaces and Decision Support			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
CERTS Area Control Error (ACE)-Frequency Real-Time Monitoring System	Available now	The ACE tool uses data visualization techniques to assess compliance with NERC reliability rules for the 143 control areas in North America. The tool relies on data generated every 4 seconds by all control areas and creates a real-time visual display of the entire power grid. This display immediately alerts NERC Reliability Coordinators to emerging frequency abnormalities within an interconnection and can pinpoint the control areas causing the violations. Armed with this information, coordinators can initiate corrective actions within minutes to prevent further degradation of system reliability.	http://certs.lbl.gov/pdf/ace.pdf
Control Room Automation (CORA), EOOS Plant Monitoring Tools	Available now	Plant monitoring software systems that include the CORA Suite and the EOOS Risk Monitor integrate seamlessly into an existing environment and quickly become indispensable to the power plant engineer. These decision support systems are intended to help control Operations and Maintenance costs.	http://www.ds-s.com/
OSI PI Process Book	Available now	The OSI PI Process Book is an easy-to-use graphics package that allows users to create dynamic, interactive graphical displays.	http://osisoft.com/Products/Products%20A-Z/
Cognos 8 Business Intelligence (BI)	Available now	Cognos 8 is a BI product that delivers the complete range of BI capabilities: reporting, analysis, scorecarding, dashboards, business event management, and data integration, all on a single, proven architecture.	http://www.cognos.com/products/cognos8businessintelligence/index.html
Gartner Dataquest	Available now	Gartner Dataquest offers a clear picture of more than 35 major IT and telecom markets with up-to-date statistics, forecasts, and analysis you can trust.	http://www.gartner.com/it/products_services.jsp
Advanced Dashboard Applications	Available now	Centerview, Obvient, Celequest, Qualitech Solutions, iExecutive Dashboard and iDashboard are applications that support data mining and dashboard presentations.	http://www.corda.com/products/index.html; http://www.obvient.com/; http://www.redorbit.com/news/technology/304838/celequest_offers_free_trial_of_operational_dashboard_software/index.html; http://www.qualitechsolutions.com/; http://www.iexecutivedashboard.com/; http://www.idashboards.com/
GridAgents	Available now	GridAgents are smart monitoring and data filtering algorithms capable of adaptive decision making.	http://www.infotility.com/; http://www.gridagents.com/ (dba as from Infotility)
Microgrid Control Software	Available now	Infotility's GridAgents Framework has built-in capability for Microgrid control.	http://www.infotility.com

Improved Interfaces and Decision Support			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Grid Computing	Available now	The Open Grid Forum (OGF) is a community of users, developers, and vendors leading the global standardization effort for grid computing. The OGF community consists of thousands of individuals in industry and research, representing over 400 organizations in more than 50 countries. Together they work to accelerate adoption of grid computing worldwide because they believe grids will lead to new discoveries, new opportunities, and better business practices.	http://www.ogf.org/About/ggf_abt_overview.php
Virtual Reality Telecommunication Systems (VRTS)	Tech transfer from telecom	VRTS will transmit human verbal and nonverbal communication messages; therefore, human-to-network interface considerations are essential. The VRTS will attempt to capture the entire human body by placing a set of sensors at the transmitting end, and will then use actuators to convey these feelings to the human body at the receiving end.	http://www.wiley.com/WileyCDA/WileyTitle/productCd-0470848863.html
Self Organizing Maps	Available now	Algorithms that use pattern recognition for presenting load profile and electrical network information.	http://www.grid7.net/; http://www.infotility.com; http://www.gridagents.com/ (dba as from Infotility)
Power System Analysis Tools	Available now	The Power System Analysis software tools are meant for modeling, design and analysis of power systems. Some main features of these tools include, but are not limited to, the following: Power Flow, Short Circuit, Stability, Protection and Coordination, Voltage Control/AGC, DC System Analysis, Optimum Power Flow, Contingency, Reliability, and Power Market Analysis. Each software tool might have different features than another software tool.	PowerWorld Simulator:www.powerworld.com/; SimPowerSystems: www.mathworks.com/products/simpower; PSCAD: https://pscad.com/products/; PSS/E: http://www.pti-us.org/pti/software/psse/sitemap.cfm; PSAF: http://www.cyme.com/software/psaf/; ETAP: http://etap.com/; ASPEN: http://www.aspeninc.com/; EasyPower: http://www.easypower.com/; NEPLAN: http://www.neplan.ch/sites/en/neplan_elec.asp; TRANSMISSION 2000: http://www.cai-engr.com/?id=content/t2k/t2000.html synerGEE:http://www.stoner.com/default.aspx?page=323; DSATools: www.dsatools.com; IPSA: http://www.ipsa-power.com/software/software.html; DAPPER: http://www.skm.com/products_dapper.shtml; Space-Time Solutions: http://www.spacetimeinsight.com/solutions.html#; PowerFactory: http://www.digsilent.com/Software/PowerFactory_Features/; MicroTran: http://www.microtran.com/products.htm; AEMPFAST: http://www.otii.com/aempfast.htm

Improved Interfaces and Decision Support			
Title	**Time to Market Use (yrs)**	**Brief Description from Cited Reference**	**References**
Power Market Software Tools/ Optimization Engines	Available now	Advanced Power Market software tools and optimization software support resource planning, unit commitment and economic dispatch, hydro and thermal scheduling, optimal power flow and security constrained dispatch, network planning, contract and risk management, power market simulation, and nuclear plant outage schedules.	http://www.ilog.com/industries/energy/; http://www.nexant.com/products/PCA/scope1.html; http://library.abb.com/global/scot/scot221.nsf/veritydisplay/581366a0c212c93ac1256fda00488562/$File/Gridview%20Brochure.pdf
Distribution System Modeling Software	Available now	These software/tools are meant for distribution system modeling, analysis, and 3-phase unbalanced power flow calculations. Features of the software include unbalanced power flow, single phase and unbalanced 3-phase modeling, optimization of distribution network, and phase swapping. Additional features are fault finding, optimal network restoration strategy, DG control analysis, fault analysis, capacitor design, load forecasting, switch management, incorporating different DG/ renewable energy models, demand side management, Wind Plant Simulations, and many more.	PNNL GridLAB-D: http://www.gridlabd.org/; EPRI openDSS: http://electricdss.sourceforge.net/; http://electricdss.wiki.sourceforge.net/; EDD DEW: http://www.edd-us.com/about.html; WindMil: http://milsoft.com/smart-grid/software-solutions/analysis-planning; ETAP: http: //etap.com/; NEPLAN: http: //www.neplan.ch/sites/en/neplan_elec.asp; SPARD mp: http://energyco.com/
Real Time Digital Simulators (RTDS)	Available now	RTDS is a tool to study both high-voltage AC and high-voltage DC (HVDC) power systems. Specifically, it is used for testing control and protection equipment; studying network performance; and educating operators, engineers, and students. The simulator features include a fully digital Electromagnetic Transient Simulator, continuous sustained real-time operation, providing accuracies over frequency ranges from DC-4kHz, and simulating a complex network using a typical time step of 50 microseconds.	http://www.rtds.com/over.htm; http://opal-rt.com/productsservices/electrical/emegasim.htm

Table 5: Improved Interfaces and Decision Support

SUMMARY

Key Technologies will fuel the development of the smart grid. Many of the required technologies are available today. Others are in various stages of development and are expected to contribute to grid modernization by the end of this decade. Other technologies currently exist only as concepts in the minds of engineers and inventors, but these technologies will be revealed in the near future, particularly as the momentum for modernizing the nation's electric system grows.

This document has been prepared to provide interested parties an inventory of technologies for each of the five Key Technology Areas that are needed to support the vision for the smart grid. It will be updated periodically. Users should consider the listed references as a starting point since technologies will advance with time.

A collection of documents regarding related aspects of the smart grid have been prepared and are available for free download at the Modern Grid website. For additional information regarding the smart grid please use the resources listed below:

The NETL Modern Grid Strategy

Website: www.netl.doe.gov/moderngrid

Email: moderngrid@netl.doe.gov

Phone: (304) 599-4273 x101