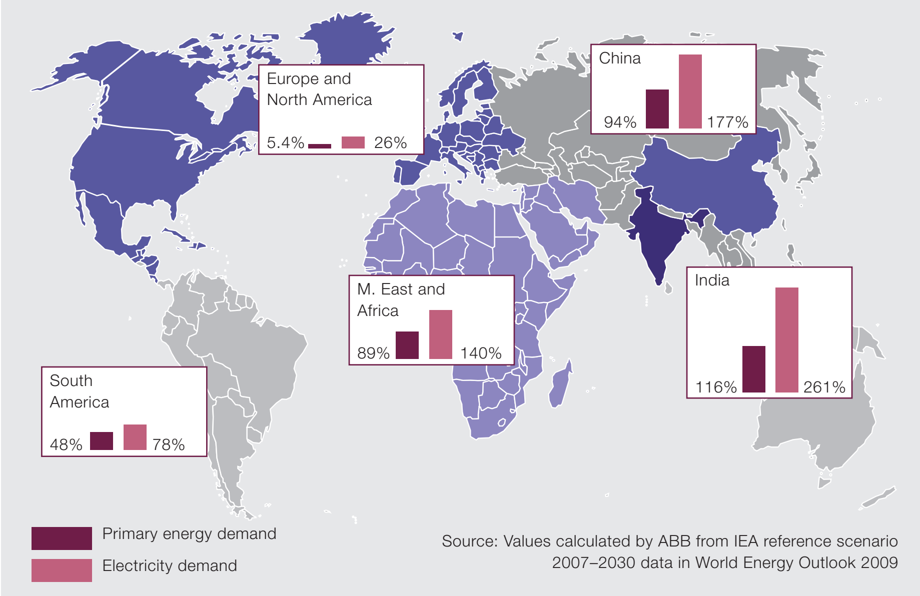
The next level of evolution

Smart grid technologies are key to supplying the world with high quality, clean, reliable and sustainable power

ENRIQUE SANTACANA, BAZMI HUSAIN, FRIEDRICH PINNEKAMP, PER HALVARSSON, GARY RACKLIFFE, LE TANG, XIAOMING FENG – Electrical power grids are critical infrastructures in all modern societies. However, many are aging and are stressed by operational scenarios and challenges never envisioned when the majority of the grids were developed many decades ago. These grids now need to be transformed into smart grids in order to meet the challenges facing developed and developing countries alike, such as the growing demand for electric power, the need to increase efficiency in energy conversion, delivery, consumption, the provision of high quality power, and the integration of renewable resources for sustainable development. The term smart grid has been frequently used in the last few years in the electric power industry to describe a digitized version of the present day power grid. Smart grids can be achieved through the application of existing and emerging technologies. However, it will take time and many technical and non technical challenges, such as regulation, security, privacy and consumer rights need to be overcome.

1 A demand growth comparison of primary and electrical energy



At the National Governors Association Convention in the United States in February 2009, the CEO of a major utility started his speech with the confession that he didn't really know what the term smart grid [1] meant [1]. Shocking as it may seem, such a confession may have absolved many in the engineering community who secretly felt the same way.

The definition of a smart grid may vary depending on where you are in the world. In the United States, for example, the following attributes are commonly cited as being necessary to define a smart grid [2–6]:

- It should be self-healing after power disturbance events.
- It should enable active participation by consumers in demand response.
- It should operate resiliently against physical and cyber attacks.
- It should provide quality power to meet 21st century needs.
- It should accommodate all generation and storage options.
- It should enable new products, services and markets.
- It should optimize asset utilization and operating efficiency.

According to a European Commission report [7], a smart grid in Europe is described as one that is:

- Flexible: It should fulfill customers' needs while responding to the changes and challenges ahead.
- Accessible: Connection access to all network users should be possible. In particular the smart grid should be accessible to renewable power sources and high efficiency local generation with zero or low carbon emissions.
- Reliable: This means the grid is secure and the quality of the supply is assured. It should be consistent with the demands of the digital age and resilient to hazards and uncertainties.
- Economical: The best possible value is provided through innovation, efficient energy management and a level playing field in terms of competition and regulation.

China, one of the biggest power-hungry economies on the planet, is also developing the smart grid concept. According to a memo issued by the joint US-China cooperation on clean energy (JUCCCE) in December 2007, "the term smart grid refers to an electricity transmission and distribution system that incorporates elements of traditional and cutting-edge power engineering, sophisticated sensing and monitoring technology, information technology and communications to provide better grid performance and to support a wide range of additional services to consumers. A smart grid is not defined by what technologies it incorporates, but rather by what it can do" [8].

The need for smart grids

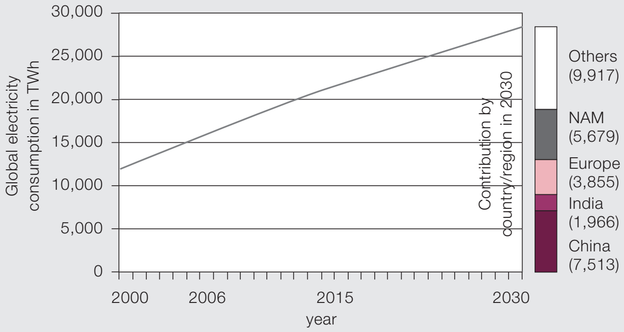
Electricity is the most versatile and widely used form of energy in the world. More than five billion people worldwide have access to electrical energy and this figure is set to increase. The level of electrical power consumption, reliability, and quality has been closely linked to the level of economic development of a country or region. According to an International Energy Agency (IEA) forecast, the worldwide demand for electrical energy is growing twice as fast as the demand for primary energy ➔ 1, and the growth rate is highest in Asia ➔ 2. Meeting this rise in demand will mean adding a 1 GW power plant and all related infrastructure every week for the next 20 years!

At the same time, an increasingly digitalized society demands high power quality and reliability. Simply put, poor reliability can cause huge economic losses. To illustrate this point, a Berkley National Laboratory report in 2005 stated that in the United States the annual cost of system disturbances is an estimated $80 billion, the bulk of which ($52 billion) is due to short momentary interruptions. The reported number of system disturbances from 2002 to the middle of 2008 is shown in ➔ 3. In addition, the threat of terrorist attacks on either the physical or cyber assets of the grids also heightens

Footnote

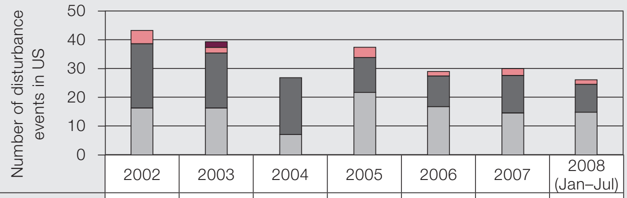
1 The term smart grid is sometimes interchanged with the terms intelligent grid, modern grid and future grid.

2 Global and regional electricity consumption



Source: IEA reference scenario in World Energy Outlook 2009

3 Reported disturbance events in the United States between 2002 and 2008



	2002	2003	2004	2005	2006	2007	2008 (Jan–Jul)
Category 5	0	1	0	0	0	0	0
Category 4	4	2	0	3	1	2	1
Category 3	22	20	19	12	11	13	10
Category 2	17	16	8	22	17	15	15

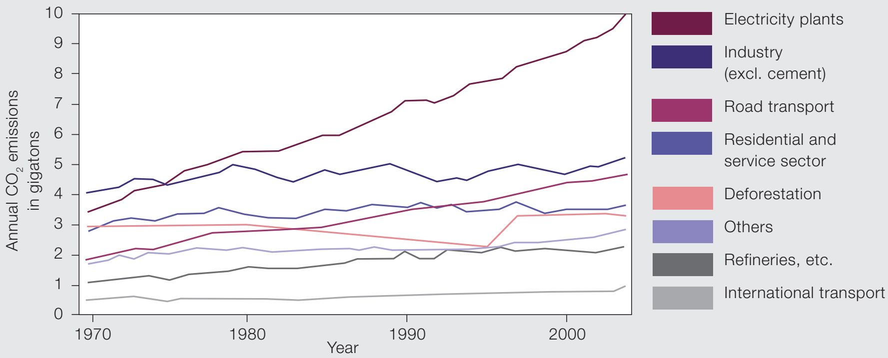
Source: NERC annual report 2008

the need for power grids that are more resilient and capable of self healing.

The impact on the environment is another major concern. CO_2 is responsible for 80 percent of all greenhouse gas effects and electric power generation is the largest single source of CO_2 emissions. The growth trend of annual CO_2 emissions (in gigatons) from electric power plants compared with the emissions from other sources is shown in ➔ 4. Shockingly, more than 40 percent of the CO_2 emissions from power plants are produced by traditional power plants. To reduce this carbon footprint while satisfying the global need for increased electrical energy, renewable energy, demand response (DR), efficiency and conservation will be needed. However, the increasing penetration of renewable energy brings with it its own challenges; for example, not only is the uncertainty in the supply increased but the remote geographical locations of wind farms and solar energy sources stress existing infrastructures even more.

These new requirements can only be met by transforming existing grids, which, for the most part, were developed many decades ago and have been showing signs of aging under increased stress. The growing consensus and recognition among the industry and many national governments is that smart grid technology is the answer to these challenges. This trend is evidenced by the appropriation – toward the end of 2009 – of more than $4 billion by the US government in grants to fund research and development, demonstration, and the deployment of smart grid technology and the associated standards [9]. The European union (EU) and China also announced

4 Growing carbon footprint in which electrical power generation is the largest single source of CO_2 emissions



Source: IPCC "Migration of Climate Change," Cambridge University Press, 2007

major initiatives for smart grid technology research, demonstration and deployment in 2009.

Smart grid challenges

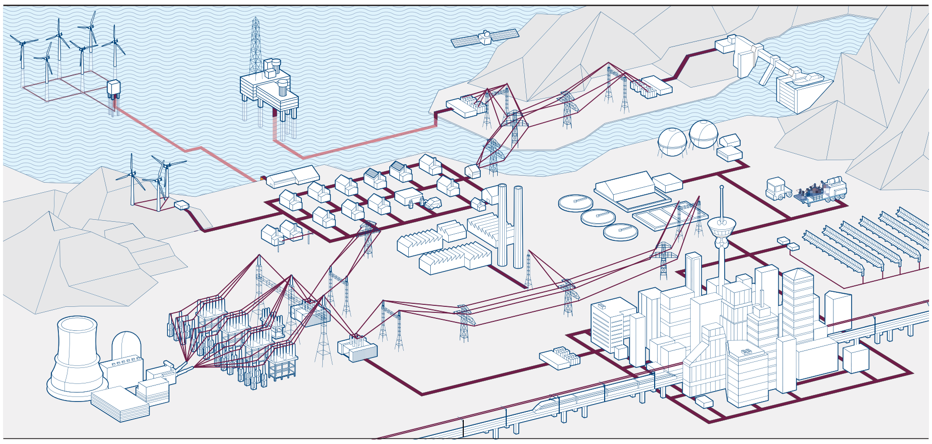
The main challenges facing smart grids, ie, doing more with less and improving efficiency, reliability, security and environmental sustainability, will depend on a combination of sensor, communication, information and control technologies to make the whole grid, from the entire energy production cycle right through to delivery and utilization, smart ➔ 5.

The most urgent technical challenges include:

- The economic buildup of grid capacity while minimizing, as much as possible, its environmental impact.
- Increasing grid asset utilization with power flow control and management.
- Managing and controlling power flow to reduce power loss and peak demand on both the transmission and distribution systems.
- Connecting renewable energy resources from local and remote

According to an International Energy Agency (IEA) forecast, the worldwide demand for electrical energy is growing twice as fast as the demand for primary energy.

5 Smart grid covers the entire generation, delivery and utilization cycle



6 Smart grid technology categories

- Decision intelligence
- Communication
- Sensor/Actuator
- Power conversion/transport/storage/consumption

7 Application examples controlled from within the decision intelligence layer

– Microgrid control and scheduling
– Intrusion detection and countermeasures
– Equipment monitoring and diagnostic evaluation
– Wide-area monitoring, protection and control
– Online system event identification and alarming
– Power oscillation monitoring and damping
– Voltage and var optimization
– Voltage collapse vulnerability detection
– Intelligent load balancing and feeder reconfiguration
– The control of a self-setting and adaptive relay
– End-user energy management
– Dynamic power compensation using energy storage and voltage-source inverters

locations to the grid and managing intermittent generations.
– Integrating and optimizing energy storage to reduce capacity demand on grids.
– Integrating mobile loads, (for example, plug-in electrical vehicles) to reduce stress on the grid and to use them as resources.
– Reducing the risk of blackouts; and when one has occurred, detecting and isolating any system disturbances and the quick restoration of service.
– Managing consumer response to reduce stress on the grid and optimize asset utilization.

Smart grid technology components

A smart grid consists of technologies, divided into four categories, that work together to provide smart grid functionalities ➔6. The bottom or physical layer is analogous to the muscles in a human body and it is where energy is converted, transmitted, stored, and consumed; the sensor and actuator layer corresponds to the sensory and motor nerves that perceive the environment and control the muscles; the communication layer corresponds to the nerves that transmit the perception and motor signals; and the decision-intelligence layer corresponds to the human brain.

The decision intelligence layer is made up of all the computer programs that run in a relay, an intelligent electronic device (IED), a substation automation system, a control center or enterprise back office ➔7. These programs process the information from the sensors or the communication and IT systems, and produce either the control directives or information to support business process decisions. These control directives, when executed by actuators, effect changes in the physical layer to modify the output from power plants and the flows on the grid.

The importance of decision intelligence and the actuator system in smart grids cannot be overstated; without controllable grid components to change the state of the power grid to a more efficient and reliable one, all data collected and communicated will be of very limited value. The more the output of power plants, the power flow on transmission lines and the power-consumption level of consumers are controlled, the more efficient and reliable grid operation can be. If, for example, the power flow control capability offered by flexible AC transmission system (FACTS) technology wasn't available, an independent system operator (ISO) would not be able to relieve transmission congestions without resorting to less economical dispatch plans. Or without the ability to control devices such as transformer tap changers or automatic switched capacitor banks, the industry will not even contemplate the development of voltage and var optimization control to reduce power loss.

For the decision intelligence layer to work, data from the devices connected to the grid need to be transmitted to the controllers – most likely located in the utility control center – where it is processed before being communicated back to the devices in the form of control directives. All of this is accomplished by the communication and IT layer, which reliably and securely transmits information to where it is needed on the grid.

However, device-to-device (for example, controller-to-controller or IED-to-IED) communication is also common as some real-time functionality can only be achieved through inter-device communications. Interoperability and security is essential to assure ubiquitous communication between systems of different media and topologies and to support plug-and-play for devices that can be automatically configured when they are connected to the grid.

Smart grid solutions

Smart grids will be built with existing and emerging technologies. ABB has been at the forefront of smart grid technology development long before the term was even coined, and the following examples support this claim.

Wide area monitoring system (WAMS)

ABB's WAMS collects information about grid conditions in real time at strategic locations. Accurate time stamps are provided by GPS satellite. It performs enhanced network analysis, incorporating phasor data to detect any instability. WAMS technology was recognized by the Massachusetts Institute of Technology (MIT) in 2003 as one of the 10 technologies that can change the world.

Supervisory control and data acquisition systems (SCADA)

SCADA systems monitor and supervise thousands of measuring points in remote terminals on national and regional grids. They perform network modeling, simulate power operation, pinpoint faults, preempt outages and participate in energy trading markets. With over 5,000 installations worldwide – more than any other supplier – the largest system in the world can be found in Karnataka, India and was delivered by ABB. It has 830 substations that supply electrical power to 16 million people ➔ 8. The system can increase operation efficiency by 50 percent and reduce "customer minutes lost" by 70 percent.

FACTS that improve power transfer

FACTS devices compensate the line inductance for maximum power transfer (series compensation) and provide power flow control capability. In some cases power system transmission capacity can even be doubled. They also mitigate disturbances and stabilize the grid (through dynamic shunt compensation). The world's largest static var compensator (SVC), with an operating range of +575 MVAr (capacitive) to –145 MVAr (inductive) at 500 kV is located at Allegheny Power (in the United States) and was delivered by ABB. In total, the company has installed over 700 systems, or more than 50 percent of all global installations.

High-voltage DC systems (HVDC)

HVDC systems convert AC from power generation to DC for transmission before reconverting back to AC for consumer use. Grids running at different frequencies (50 or 60 Hz) can therefore be coupled, while instabilities on one part of the grid can be isolated and contained. HVDC is ideal for transporting power from challenging locations (eg, subsea) and over long distances with low losses; for example, by installing an ultra high-voltage direct current (UHVDC) connection, as is the case with the 2,000 km link between Xiangjiaba and Shanghai in China, it is envisioned that transmission losses will be reduced by over 30 percent! One of the world's longest and most powerful transmission systems, supplied by ABB, transports 6,400 MW and operates at ±800 kV.

HVDC also incurs lower infrastructure costs (fewer and smaller pylons and fewer lines) and this offsets the higher investment needed in converter stations. With more than 50 years experience in HVDC technology, ABB is widely recognized as the market and technology leader in this area.

Fault detection and system restoration

A substation automation system is a key component of ABB's smart grid portfolio. It performs data acquisition, remote communication, supervision control, protection and fault evaluation. ABB's substation automation systems are compliant with the IEC 61850 communication standard to assure interoperability with similar compliant products. With more than 700 such systems sold to date, one of the world's largest substation automation systems, installed by ABB, is situated in Moscow.

Process control in power generation

The optimization of auxiliary systems in power plants offers significant savings when one considers that up to 8 percent of a plant's production may be consumed by these systems. Additional savings can be realized by improving both the combustion system process and start-up times for boilers. Savings in both thermal and electrical energy can be achieved using existing ABB technologies.

Driving toward industrial efficiency

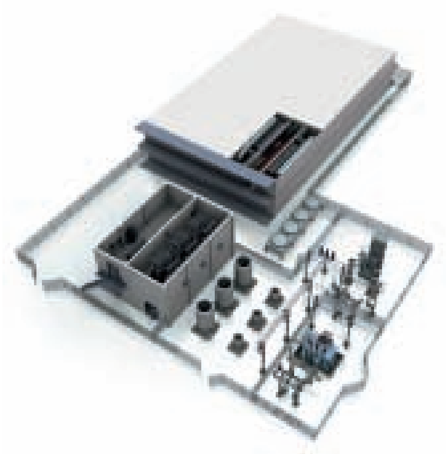
The optimization of motor-driven systems offers the single largest energy-saving potential in industry. The installation of drive systems alone could save around 3 percent of energy, equivalent to the output from more than 200 fossil power plants (each producing 500 MW). The global installed base of ABB drives provides an annual saving of 170 million tons of CO_2, which corresponds to 20 percent of total emissions in Germany. Process control is another effective and immediate way for industry to achieve energy savings of approximately 30 percent using existing ABB technologies.

Building control for optimal performance

According to the World Business Council for Sustainable Development (WBCSD), automation systems installed in buildings can reduce energy consumption by up to 60 percent, while global consumption could fall by as much a 10 percent. ABB building control systems allow the individual adjustment of rooms and appliances to ensure energy consumption is at its most efficient. For example, using

8 The control room at Karnataka Power

9 An impression of an SVC Light® with Energy Storage installation



Smart grid technology is not a single silver bullet but rather a collection of existing and emerging technologies working together.

ABB's i-bus/KNX technology, which is used in hotels, airports, shopping centers and houses around the world, energy consumption was reduced by 30 percent in several large buildings in Singapore.

ABB has been at the forefront of smart grid technology development long before the term was even coined.

Solar and hydropower

ABB supplies power plant control for hydro, wind and solar plants, as well as tailor-made long-distance connections to integrate green energy sources to the grid. Such an automation system and associated electrical equipment has already been delivered to Europe's first large-scale 100 MW solar plant in Spain (Andasol). In Algeria, the complete plant control for the world's first integrated solar combined cycle plant (175 MW) has also been supplied by ABB, while a turnkey 1 MW solar concentration plant, with a performance ratio of 80 percent, was constructed in Spain in record time. To date, ABB has connected 230 GW of renewable energy to the grid.

Offshore wind parks

ABB is the world's largest supplier of electrical equipment and services to the wind energy industry. It supplies complete electrical systems for wind generation as well as subsea connections to onshore grids. HVDC Light®, with its oil-free cables and compact converter stations, will connect the Borkum offshore wind park, one of the world's largest with a capacity of up to 400 MW and located 125 km out to sea, to the German national grid.

Energy storage to bridge outage periods

The total electrical power input and output on an interconnected grid must be closely balanced at all times. Any imbalance will cause the system frequency to deviate from the normal value of 50 or 60 Hz. Balancing power is a major issue for utilities and is especially critical as large amounts of intermittent wind and solar energy are added to the supply mix. Bulk storage of electrical energy helps to compensate for any imbalance in the system and reduces the need for expensive spinning reserve capacities. Battery systems with DC to AC converters are one way of coping with the problem. The world's largest battery energy storage system [2] (BESS) is located in Fairbanks, Alaska and was installed by ABB. This installation can supply 26 MW of power for 15 minutes, giving the utility enough time to bring back-up generation on line in the event of an outage.

Integrating storage with FACTS

FACTS devices regulate power flow or voltage in a grid to maximize capacity by regulating the line's reactance or by injecting reactive power. By combining a battery storage system with FACTS (to create SVC Light® with Energy Storage [3]), active power can be injected or extracted as needed and quickly ➔ 9. In addition, it provides power balancing, peak power support, and voltage and power quality control. This solution will be in operation in 2010. Future systems will operate in the MW range.

Building the grid of the 21st century

Smart grid technology is not a single silver bullet but rather a collection of existing and emerging technologies working together. When properly implemented, these technologies will increase efficiency in production, transport and consumption; improve reliability and economic operation; integrate renewable power into the grid; and increase economic efficiency through electricity markets and consumer participation. A century of technological leadership has equipped ABB with a broad portfolio of products and systems that will be called upon to build and operate the smart grids of the 21st century.

Footnotes

2 BESS comprises a massive nickel-cadmium battery, power conversion modules, metering, protection and control devices, and service equipment. In operation, BESS produces power for several minutes to cover the time between a system disturbance and when the utility is able to bring backup generation online.

3 For more information, refer to "Storage for stability: The next FACTS generation" on page 24 of this issue of *ABB Review*.

Enrique Santacana
President & CEO, ABB Inc.
Cary, NC, United States
enrique.santacana@us.abb.com

Bazmi Husain
Friedrich Pinnekamp
ABB Smart Grids
Zurich, Switzerland
bazmi.husain@ch.abb.com
friedrich.pinnekamp@ch.abb.com

Per Halvarsson
ABB Power Systems, Grid Systems/FACTS
Västerås, Sweden
per.halvarsson@se.abb.com

Gary Rackliffe
ABB Power Products
Raleigh, NC, United States
gary.rackliffe@us.abb.com

Le Tang
Xiaoming Feng
ABB Corporate Research
Raleigh, NC, United States
le.tang@us.abb.com
xiaoming.feng@us.abb.com

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