Electrical energy

The challenge of the next decades

Bernhard Jucker, Peter Leupp, Tom Sjökvist

The electricity industry is driven by a number of different forces, and it faces a series of challenges that will change the way that electrical energy is produced, distributed and used. With demand growing at a constant rate and with most of that growth taking place in developing countries, the regional differences in the way electricity is used are likely to be accentuated. In the mature economies the aging infrastructure poses a challenge and the request for technologies that protect the environment and reduce the energy intensity is high. In the developing and fast-growing economies, the vast need for electrical energy drives huge investments in new infrastructure for generation, transmission and distribution.

Although the energy mix for power generation is not expected to change significantly, those countries that increase the amount of renewable energy in their mix will need to address grid reliability. Transmission and distribution grids in many parts of the world are operating close to capacity and although new grids are being built in the rapidly growing Asian economies, they are not being built fast enough to meet the escalating demand. To reduce local energy shortages or provide a better optimization base for utilities, either inter-connections between grids will be necessary or other local resources for generating electricity have to be promoted.

The top priority for all countries will be to ensure a reliable supply of electric power. The cost involved in refurbishing grids and new grid installations is a major challenge. This challenge is getting harder for the equipment manufacturer due to the shortage of materials used and the fact that ageing assets require more and more maintenance. To reduce operating costs and increase output there will be a tighter focus on minimizing power losses and on changing the way energy is used and marketed.

Political drivers

In most emerging economies and in some mature economies, the demand for electricity increases in relation to growing gross domestic product (GDP) per capita 1. Governments attempt to keep pace by providing a functioning electrical infrastructure that can extend over vast geographic expanses, as in China and India, or across national borders, as in Africa or the Middle East.

In mature economies, investment in power networks consists mainly of bottleneck removal and network improvements to secure supply reliability and prevent blackouts. Deregulation was introduced to encourage investment in electrical infrastructure. This has not materialized, with the result that an imbalance exists between lacking generation capacity and increasing consumer demand in many parts of the developed world.

The fact that critical applications like hospitals, the manufacturing and process industries, and Internet and telecommunications infrastructure are dependent on electricity makes supply reliability a priority for many countries. Whether the primary energy sources are nuclear power, wind energy or coal, for example, in those cases where generation and consumption are not collocated, countries must trigger investment in the transmission and distribution network to facilitate the delivery of larger volumes of power.

> The top priority for all countries will be to ensure a reliable supply of electric power.

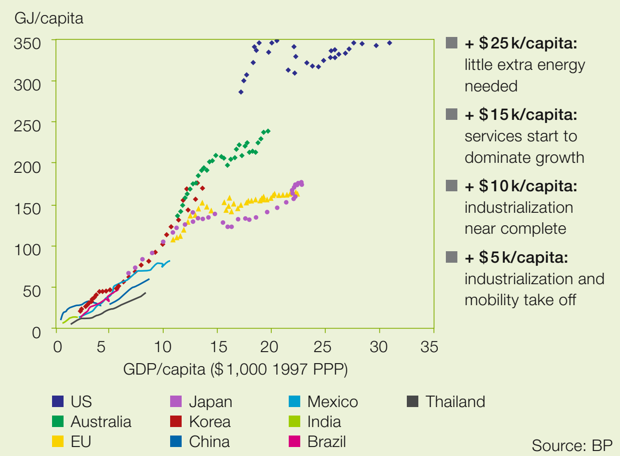
Network interconnections are driven by several key political factors. First, the need for supply security is strongest in those countries where there is a shortage of power generation resources. Getting connections to other grids could help. Second, interconnections make it possible to stabilize a national grid without making a major investment by using foreign capacity reserves. And third, interconnections in some large political structures like the European Union are a logical consequence of the political integration of neighboring nations.

An important argument for cross-border operating utilities is the increased flexibility and the better options to plan new generation capacity.

Environmental issues are also driven by political considerations. The Kyoto Protocol and other international accords are driving new types of energy generation, in particular renewable energies with low CO_2 emissions. These agreements have a direct influence on the types of energy selected for state subsidies and on the technologies on which companies focus their research and development programs.

Policies intended to stimulate the growth of renewable energy can have diverse effects. A decision to replace five or ten percent of a country's electrical supply within a short timeframe can only be achieved by building large offshore wind parks. ABB recently got an order to connect the world's largest windpark in the North Sea to the German electrical grid. Additional generating capacity will be necessary to ensure that there is sufficient back-up power and that grid stability is not weakened. On the other hand, wind parks are not always popular. People do not usually like wind turbines close to their homes and often oppose the building of new nuclear power plants, even though both alternatives are environmentally friendly with respect to CO_2 emissions and global warming.

1 The connection between gross domestic product and energy consumption per capita reflects on the status of development of a society



Different regions prioritize different aspects of the environment. While the presence of distribution lines in the streets of towns and cities is not acceptable in Western Europe, it is not an issue in the United States and other parts of the world. For transmission lines the issue of the "right of way" is significant[1).

The regularity and effects of blackouts – as in Europe in 2003 – have triggered

Footnote

[1)] See "Transport or transmit?" on page 44 of this edition of *ABB Review*.

A complete supply chain

a political debate about the reliability and robustness of electricity networks. In some countries new legislation is imposing heavy financial burdens on utilities that fail to deliver power to consumers; in others, utilities have made agreements with large industrial consumers to shed load in overload conditions in order to secure network stability and prevent large-scale blackouts.

Attempts to control the power factor of industrial and electrical equipment are also making progress. Legislation, energy taxes and information campaigns have all influenced customers into selecting variable-speed drives and high-efficiency motors, and consumers into choosing energy-efficient home appliances [1].

Economic drivers
Strongly connected to economic growth, especially in the rapidly emerging economies, is the demand for electrical energy. The International Energy Agency (IEA) estimates that net electricity consumption in the emerging economies will grow at an average rate of about 4 percent a year between 2007 and 2030 2. In contrast, demand in the mature economies is predicted to rise by an average of 1.5 percent a year, and in the transitional economies of Eastern Europe and the former Soviet Union (EE/FSU) by an average of 3.1 percent. China and the United States are expected to lead the projected growth in consumption, adding almost three and two billion kilowatt hours, respectively, to their annual net consumption levels over the 23-year period 3.

Predictions for growth in net consumption in the emerging economies are based on projected increases in GDP and population. GDP growth in turn is dependent on access to reliable supplies of electricity. Because of the connection between reliable electricity supply, GDP growth and rising living standards, many emerging economies are making efforts to increase the capacity and reliability of their power networks.

In China and India this is leading to the construction of new power plants in remote locations close to primary energy sources. New transmission lines with the capacity to deliver large volumes of power are therefore required[2].

In the United States strong economic growth throughout the country is increasing the need for more generating capacity, mostly provided by upgrading existing plants. Demand for power is particularly strong in the commercial sector where average increases of 2.4 percent a year are offsetting efficiency gains in electrical equipment. Growth in the industrial and residential sectors is expected to be moderate.

Western Europe and Japan are expected to have the slowest growth in demand at 0.4 and 0.6 percent, respectively, in the residential sector, and 0.8 and 0.9 percent, respectively, in the commercial sector. Static or slightly declining population levels, expansion of information and communication technology (ICT) infrastructure, and the switch to economical heating and cooling devices are the main reasons for the flat demand curve.

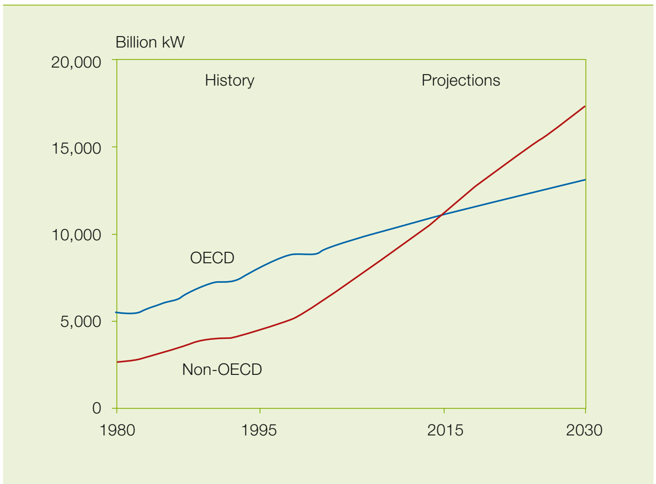
The vast growth in demand for electrical energy is expected to continue over the next two decades and is estimated to require an investment of $ 10,000 billion in new electrical infrastructure, about half of which is needed for transmission and distribution systems.

> Many emerging economies are making efforts to increase the capacity and reliability of their power networks.

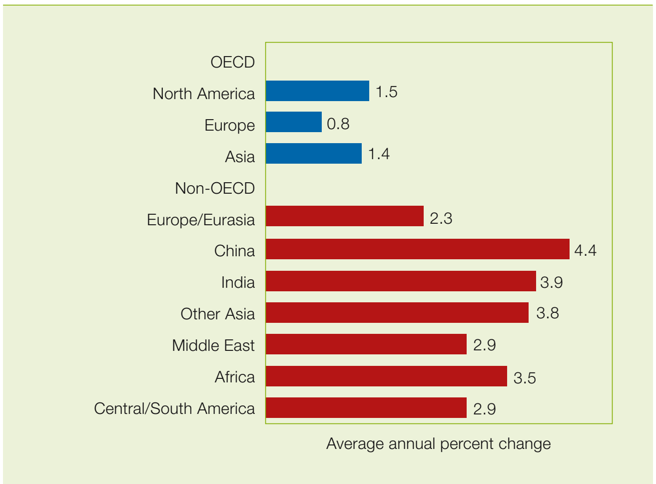
In mature economies the tendency is to get as much energy as possible out of the existing system. Building new transmission lines is difficult for a variety of reasons, an important one being the "right of way" issue. There is little incentive for utility companies to invest in transmission and distribution infrastructure, as long as the investor is not the one who profits from the investment. It is more economical for them to squeeze more capacity out of existing assets.

Footnote
[2] See "Transport or transmit?" on page 44 of this edition of *ABB Review*.

2 World electric power generation by region (Source: IEA *World Energy Report 2007*)



3 Projected growth rates in electricity generation for OECD and non-OECD countries (Source: IEA *World Energy Outlook 2007*)



A shortage of electricity in periods of high demand can lead to brownouts or blackouts. A recent study by the Union for Coordination of Transmission of Electricity (UCTE) in 2005 estimates that in 2015 there will be insufficient reserves of electrical power in all European countries. The report assumes that current plans to increase generating capacity will be implemented. The most economical solution to an energy shortage is to import power from a neighboring country. Connection to an adjoining grid is an efficient way for a country to stabilize its grid if spinning reserves are insufficient.

In mature economies there is a tendency to take electricity supply for granted. This was given a severe blow in 2003 when a series of widespread and high-profile blackouts drew attention to the vulnerability of electrical infrastructure. It led to the realization that there is a need to replace or upgrade ageing assets on a large scale in the short to medium term.

There was a similar wakeup call in China. Three-quarters of the electricity consumed in China is used for manufacturing and heavy industry. When power shortages occurred in the summer of 2004, some 6,400 industrial plants in Beijing alone were shut down for a week and their operations staggered for the duration of the summer to avoid consumption peaks. Unless investment in electricity infrastructure keeps pace with demand, shutdowns and rolling blackouts could have a significant and detrimental effect on the country's economy.

China's 11th five-year plan targets an increase in generating capacity of 570 gigawatts by 2010. This is equivalent to an increase of roughly eight percent a year and will require annual investments of $ 20 billion to $ 30 billion. It appears, however, that building more power plants will not solve all of China's electricity problems. Equally important is the construction of transmission lines to link the plants to consumers. The State Grid Corporation of China estimates that investments of $10 billion a year will be needed to expand and upgrade the country's power transmission grid.

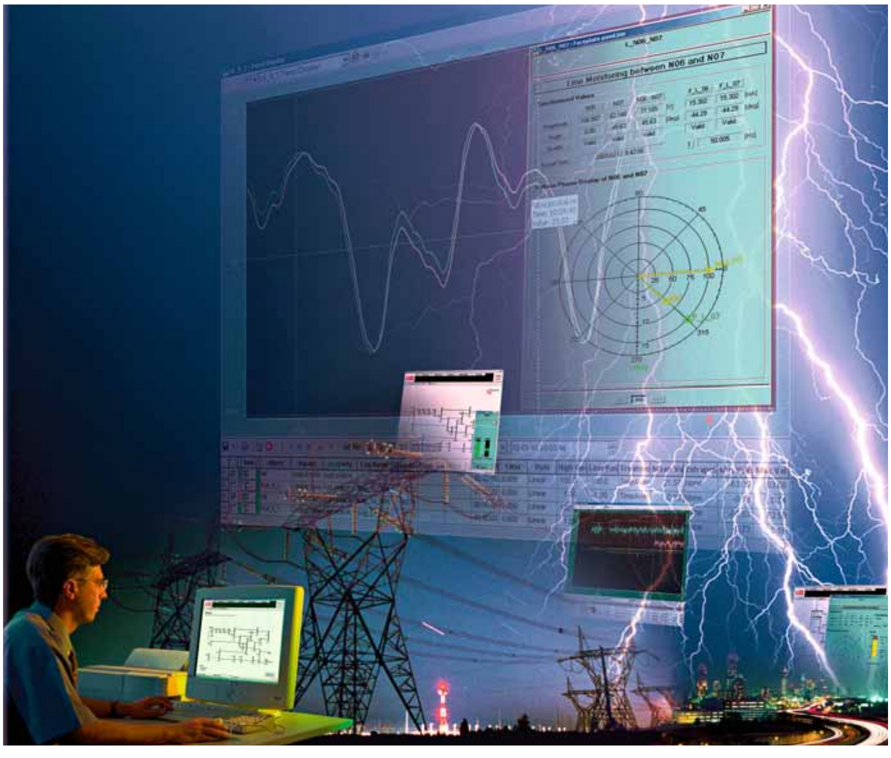
Some countries have introduced penalties for utilities that fail to meet demand. In Sweden, electric utilities have to compensate households with a sum equivalent to approximately one month's electricity consumption for every day that the household is without power. This is a strong incentive for utilities to improve grid reliability.

Many utilities now see reliability as one of their most pressing concerns. The impact of poor reliability on society as a whole can be crippling. The blackout on August 14, 2003 in the United States is estimated to have incurred costs and lost revenues of $ 7 billion to $ 10 billion, and is attributed, as are most large-scale blackouts, to underinvestment in transmission and distribution capacity and the use of outdated technology and simply wrong operation procedures.

Like reliability, the quality of the power delivered is increasingly driven by economic considerations. Some industries, such as printing and petrochemicals but also hospitals and other critical systems, require high levels of power quality. A Nordic Council survey estimates that the damage caused by a voltage sag (50 percent, 200 ms) for an average industry is as high as $ 4.50 per kW installed. The demand for power quality is particularly strong in mature economies with extensive amounts of sensitive ICT infrastructure, but is likely to become a global issue in the decades to come.

Attempts to reduce system losses are also driven by environmental factors. Transmission and distribution systems tend to lose 6 to 7 percent of the electricity they transport. Approximately 70 percent of those losses occur in the distribution system, which is more extensive than the transmission system and operates at a lower voltage (losses in lines are inversely proportional to the square of the voltage, ie, doubling the voltage reduces losses to a quarter of their original value). Losses of more than 30 percent are estimated for developing countries, although it is important to distinguish between technical losses and commercial losses (the latter cannot be accounted for and are usually due to illegal connections).

Technical losses are rarely above 20 percent. Technologies such as high-quality transformers and reactive power compensation can reduce them to 5 to 7 percent. High levels of commercial losses can be devastating for system operators: If they cannot collect revenues, they cannot generate sufficient capital for investment.



It is not only utilities that are keen to reduce losses. Electrical energy savings have a direct impact on the bottom line of industrial plants, commercial businesses and households. This drives the demand for energy-efficient electrical equipment like motors, drives and consumer appliances.

Electrical energy savings have a direct impact on the bottom line of industrial plants, commercial businesses and households.

The market naturally expects the cost of new grids and grid components to be as low as possible. With the price of raw materials like copper rising, their replacement with low-cost or better alternatives is an ongoing issue. Similarly the replacement of hazardous materials and the avoidance of penalties or taxes for excessive greenhouse gas emissions are strong economic drivers.

Technology drivers

Many new technologies, especially those for ICT devices and systems, require substantial amounts of energy. The growing number of new consumer products and more powerful home computers also use large amounts of electrical energy. In Germany, the estimated energy requirement of ICT devices is expected to grow by about 4 percent a year and account for 11 percent of the country's energy consumption in 2010.

New technologies for industrial and commercial applications like integrated heating and cooling systems in buildings, improved battery technology for hybrid vehicles, and the widespread introduction of high-speed trains will increase the demand for efficient electric power. Technological developments in wind power will change energy flow patterns in grids, as will new types of power generation on the low-voltage side and large-scale wind farms.

Progress in static var compensation and power storage technologies will enable new sources of electrical energy to be connected to existing grids. New types of batteries that are more compact than conventional lead-acid technology are already making an impact. For instance, the 40 MW battery at Fairbanks, Alaska, provides backup power for up to seven minutes for a community of 80,000 people [2]; and a new compact lithium ion substation battery with greater capacity and reliability is operating successfully in a pilot installation in Sweden. These installations are rather the exceptions and did not find a wider application so far. Flywheels, compressed air, pumped hydropower or compressed air storage are other means of storing energy through conversion.

Another energy storage method is hydrogen. Electricity is supplied to an electrolyzer, which divides water into hydrogen and oxygen, its two constituent parts. The hydrogen can then be stored and reconverted into electricity by fuel cells when needed. The overall efficiency of this storage method is currently rather low at about 25 percent. It remains to be seen whether hydrogen will replace electricity as a better means to transport energy. Major progress in the technology is not expected within the next few decades.

Phase-shifting transformers and series compensation are long-established methods for increasing power transfer in electrical grids. Power electronics have made it possible to control grids and new FACTS (flexible AC transmission systems) are improving controllability [3]. New concepts like the unified power flow controller (UPFC) and the variable frequency transformer (VFT) have to show their customer acceptance yet. Monitoring systems like phasor measurement units are slowly being installed in power networks, which will, when fully deployed, increase the possibility of operating a system close to its limit [4].

New technologies will also improve maintenance. The switch from oil-based to dry insulation and from spring drives to electrical drives in circuit breakers are examples, as is the introduction of information technology into maintenance processes. Online analysis of primary equipment such as transformers is facilitated by software that assesses the condition of the equipment in real time. Risk analysis software for the preventive maintenance of critical grid components is also available and under continuous development [5].

Technologies that save energy or improve efficiency are becoming more widespread [6]. Low-loss and energy-efficient power semiconductors are reducing losses in the grid, and material processing like laser-cut sheet metal for transformers and improved material properties may result in additional efficiency gains. Traditional lightbulbs are being replaced by electroluminescent lighting and more recently by bright LEDs. And continuous reductions in energy loss are being achieved by advanced motors and power-electronics-based variable-speed drives.

The use of superconducting materials is another way to reduce losses in power grids. Research laboratories are making progress and there are now several types of superconducting materials available, of which magnesium diboride is a recent addition. Efficient cooling and an interface with existing 400 kV systems (a low-voltage/high-current system to a high-voltage/low-current system) and improved system characteristics will have to be developed before real progress with superconducting transmission can be made.

Compact circuit breakers and gas-insulated switchgear have reduced substation footprints and made it possible to build substations indoors – important factors in urban environments and megacities where space is expensive and in short supply[3] [7]. By replacing oil-paper insulation with cross-linked polyethylene (XLPE) insulation, the viable length of AC cables has increased by a factor of two and made underground high-voltage direct current (HVDC) cables economical for long distances [8].

New HVDC technology reduces the footprint of existing HVDC by a factor of three [9]. This is especially important for applications where space is critical. Some electrical equipment footprints are determined by the noise level they inject into the environment. New technologies have reduced noise in shunt reactors by 15 dB in the last 20 years.

Technical progress with new materials makes for better applications. Dry materials like XLPE are replacing oil and other wet materials; they reduce the risk of fire and enable equipment to be located closer to buildings. The standard epoxy resin commonly used as insulating material is being replaced by modern thermoplastics that bring more flexibility into manufacturing.

Information technology has opened up new ways for electricity to be traded as a commodity. Utilities are equipping households with meters that measure hourly consumption, and hourly trading is on the agenda to enable consumers to buy the cheapest, greenest or locally produced power. Reserach and development initiatives on "smart" or "self-healing" grids that improve supply reliability are also driven by advances in information and communication technology[4].

Prepared for the future

ABB, as a technology and market leader for all the issues discussed here, is very well positioned to contribute cutting-edge technology to the world's major energy challenges. ABB's local presence in all the markets gives customers the valuable advantage of fast and focused service. ABB works together with its customers to find the best solutions tuned to their local needs and to develop systems that work effectively across borders, whenever global approaches are appropriate.

Bernhard Jucker
ABB Power Products

Peter Leupp
ABB Power Systems

Tom Sjökvist
ABB Automation Products

Footnotes

[3] See "Substation evolution" on page 34 of this edition of *ABB Review*.

[4] See "When grids get smart" on page 44 of this edition of *ABB Review*.

References

[1] *ABB Review Special Report* Motors and Drives (2004), 1–64.
[2] **DeVries, T., McDowall, J., Umbricht, N., Linhofer, G.** Cold storage. *ABB Review* 1/2004, 38–43.
[3] **Grünbaum, R., Petersson, Å., Thorvaldsson, B.** FACTS. *ABB Review* 3/2002, 11–18.
[4] **Korba, P., Scholtz, E., Leirbukt, A., Uhlen, K.** Combining forces to provide stability. *ABB Review* 3/2007, 34–38.
[5] **Eklund, L., Lorin, P., Koestinger, P., Werle, P., Holmgren, B.** On-site transformation. *ABB Review* 4/2007, 45–48.
[6] *ABB Review* 2/2007, Energy efficiency, 1–92.
[7] **Frei, C., Kirrmann, H., Kostic, T., Maeda, T., Obrist, M.** Speed and quality. *ABB Review* 4/2007, 38–41.
[8] **Ravemark, D., Normark, B.** Light and invisible. *ABB Review* 4/2005, 25–29.
[9] **Nestli, T. F., Stendius, L., Johansson, M. J., Abrahamsson, A., Kjaer, P. C.** Powering Troll with new technology. *ABB Review* 2/2003, 15–19.

Factbox About the authors

Bernhard Jucker is Executive Vice President and member of the Executive Committee, responsible for the Power Products division

Peter Leupp is Executive Vice President and member of the Executive Committee, responsible for the Power Systems division

Tom Sjökvist is Executive Vice President and member of the Executive Committee, responsible for the Automation Products division