

More and more electricity will be generated in the future. However, old grids can scarcely handle the electricity generated today. Electric "gridlock" is a real threat.



Our power grids are facing new challenges. They will not only have to integrate large quantities of fluctuating wind and solar power, but also incorporate an increasing number of small, decentralized power producers. Today's infrastructure is not up to this task. The solution is to develop an intelligent grid that keeps electricity production and distribution in balance.

Switching on the Vision

Motorists who venture into the maze of a major city are part of a larger whole. Tens of thousands of vehicles stream along highways from all directions and find their way through a dense network of roads. But keeping that network flowing is no easy task. Already hopelessly clogged under the best of circumstances, such networks can easily face gridlock. All it takes is a few fender benders — to say nothing of circumstances such as a subway strike or a snow storm. As a result, sooner or later, every city government must decide whether to expand its transportation infrastructure or face collapse.

The situation with our power grid is similar. Electricity flows on copper "highways" from power plants to centers of demand. Along the way, it passes through various "road networks" that are separated by substations. These facilities function as traffic lights or railroad switches while also adjusting the electricity before forwarding it to the next grid. In the highest voltage alternating current lines, electricity flows at 220 to 380 kilovolts (kV) across hundreds of kilometers from power plants to substations, where the voltage is reduced to 110 kV before the electricity is then fed into the what is called the distribution or high-voltage grid. This grid is used for the general distribution of power to population centers or large in-

dustrial sites, where, depending on the region, the voltage is stepped down again to between six and 30 kV for the medium-voltage grid. This is followed by local distribution. Here, substations reduce the voltage to 230 and 400 volts and send the power into the low-voltage grid, which feeds consumers' outlets.

Needed: Electricity Highways. Until now, electrons have flown relatively smoothly through Europe's grids, despite the fact that many of the continent's power lines are now over 40 years old. Gridlock is inevitable, however, as traffic continues to increase. According to the International Energy Agency, the European Union generated roughly 3,600 terawatt hours (TWh) of electricity in 2006. This is expected to reach 4,300 TWh by 2030.

In addition, the energy mix is getting more environmentally friendly. In 20 years, some 30 percent of the world's electricity is expected to come from renewable sources. Today the figure is only 18 percent. But as the percentage of electricity generated by renewables grows, so does the instability of the network. Because eco-friendly electricity is primarily generated by wind farms (see p. 16) much more energy than can be used is pumped into high voltage network in stormy weather, while supply cannot be guaranteed on calm days.

In addition to being able to accommodate a fluctuating supply of wind-generated electricity, tomorrow's grids will have to incorporate a growing number of small, regional power producers. "The generation of electricity will become increasingly decentralized, incorporating small solar installations on rooftops, biomass plants, mini cogeneration plants and much more," says Dr. Michael Weinhold, CTO of the Siemens Energy Sector. "As a result, the previous flow of power from the transmission to the distribution grid will be reversed in part or for periods of time in many regions." According to Weinhold, our grid infrastructure is not yet prepared for that.

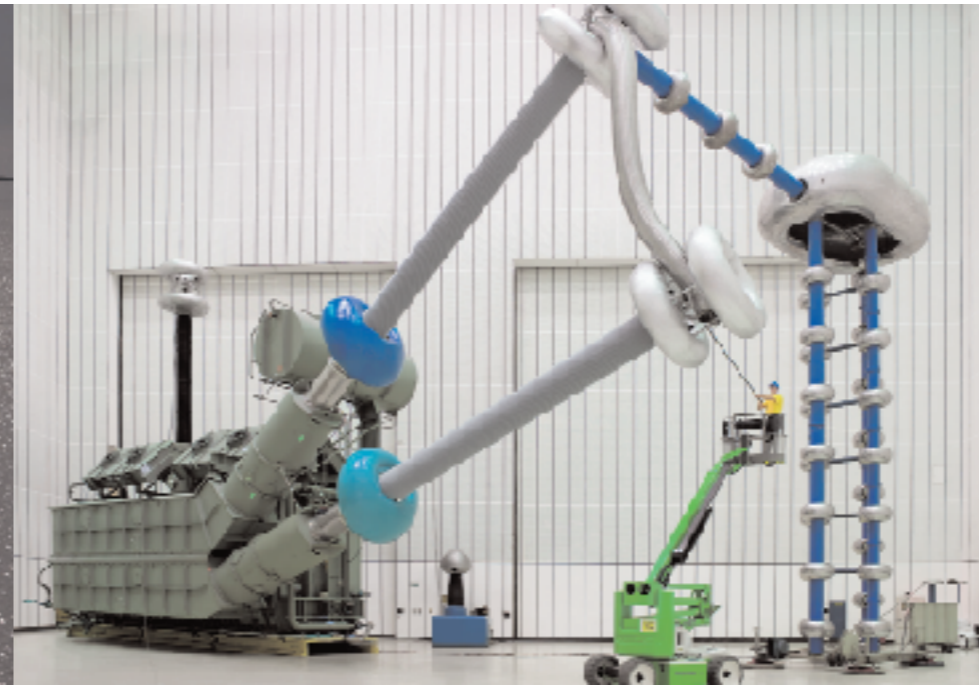
Grid operators and governments agree on how the challenge should be met. In addition to a massive expansion of electricity highways, the grids must undergo a fundamental change. "Right now they are not very intelligent," says Weinhold. "The level of automation for the system as a whole is very low." The low-voltage distribution grid, in particular, is often a total mystery to utilities. Because it includes hardly any components capable of communication in its present configuration, a lot of important information remains concealed, such as the actual amount of energy being used by consumers and the condition and efficiency of the line system.

According to an Accenture study, up to ten percent of energy disappears from the grid either due to inefficiency or electricity theft without being noticed by power providers. In large cities in some developing nations, as much as 50 percent of electricity disappears this way, and power providers are often unaware of outages — at least until the first complaint is received.

With a view to heading off impending problems, in 2005 the European Union came up with a concept, which it called the "smart grid" — a vision of an intelligent, flexibly controllable electrical generation and distribution infrastructure. "The energy system plus information and communications technology all enter into a symbiosis in the smart grid," says Weinhold. "Not only does this make the grid transparent and thus observable, it also makes it easier to monitor and control."

Governments and companies are committing large amounts of money to ensure that this vision becomes reality. The U.S. Department of Energy, for instance, has provided roughly \$4 billion in subsidies for smart grid projects in the U.S. German energy utilities are planning to invest roughly €25 billion in smart grid technology by 2020 (see p. 42). Key components for the power grid of the future are already available and have even been installed on a limited basis in some countries. One example is smart meters — intelligent, electronic electric meters (see p. 36).

"Smart metering is a key technology for the smart grid," says Eckardt Günther, who heads the Smart Grid Competence Center at Siemens Energy in Nuremberg, Germany. "With smart metering, energy providers and consumers



Most of tomorrow's electricity will be generated from renewables such as wind. With HVDC technology, the power can be transmitted over long distances (here an 800 kV transformer).

Sebnem Rusitschka of Siemens Corporate Technology is also convinced that tomorrow's grid will have to be smart. As part of the E-DeMa (development and demonstration of locally-produced energy marketplaces) project, which is subsidized by the German federal government, Rusitschka is responsible for developing the information and communication interface between smart meters, the system for meter data management, and the electronic marketplace. "Among the things we are investigating is how these digital links need to be configured, i.e. what data should be trans-

ducers such as cogeneration plants, wind, solar, hydro or biomass plants, which have previously fed their power into the grid individually and inconsistently, could be connected to form a virtual network. "This would allow them to bundle their power and sell it in a marketplace that is inaccessible to small suppliers," says Günther. The grid would benefit too. "Consolidated into a virtual power plant and acting as a flexible unit, small plants could make balancing power available and thus help to stabilize the grid," says Günther. Balancing power is provided in addition to the base load to cover peaks in demand. As this type of power requires power plants that can begin producing energy quickly, the price for a kWh of balancing power is much higher than for a kWh of base load power. Base load power is generally provided by the workhorses of power generation — coal-fired or nuclear power plants that run around the clock.

Stability will be crucial to tomorrow's grid. But intelligent systems alone will not be enough to manage the large amounts of energy provided by the growing numbers of wind farms or solar-thermal power plants. "There is also work to be done on the hardware side," says Weinhold. "We need to greatly expand the number of power lines, as physics limits the transmission of electrical energy to wires or cables."

According to the German Energy Agency (DENA) study, some 400 kilometers of high-voltage grid needs to be reinforced and an additional 850 kilometers of lines need to be

erected by 2015 simply to transmit the wind energy that will be generated in Germany.

Super Grids. The steadily increasing distances between power generation sites and consumers must also be bridged. One element of a solution to this problem could be high-voltage direct current (HVDC) transmission, which is capable of transporting large amounts of electricity across thousands of kilometers with low losses. Siemens is currently building the world's highest capacity HVDC transmission system in China (p. 24). The system is sched-

uled to begin transmitting electricity generated at hydroelectric plants with a record voltage of 800 kV across a distance of 1,400 kilometers by 2010. Weinhold believes that these electricity highways will not only cross borders in the future, but will link entire continents. "We will see the establishment of super grids in regions that can be interconnected across climate and time zones," he says, adding that this would allow seasonal changes, times of day and geographical features to be used to their optimal benefit. Super grids could be used to transport enormous quantities of solar energy from

Northern Africa to Europe, as described in the Desertec project (see p. 19). "Electricity will draw the world together," predicts Weinhold.

In addition to new electricity highways, tomorrow's grid will need more buffers to stop it from bursting at the seams. Intermediate storage is needed for the excess power fed into the grid by fluctuating energy sources (see p. 31). Traditionally, this has relied on pumped storage power plants, but there is hardly any capacity for further expansion in Central Europe. As a result, wind farms will either have to be shut down to prevent them from overloading the grid during periods of overproduction or producers will have to pay someone to take the electricity.

One future solution could be electric cars, which temporarily store excess energy and later return it to the grid when needed — at a higher price (see p. 44). For example, 200,000 electric cars connected to the grid could make eight gigawatts of power available very quickly. That would be more than is currently required in Germany. As part of the EDISON project, in which Siemens is also participating, testing will begin on the electric cars concept and other solutions in Denmark in 2011.

It is abundantly clear to Weinhold that we are moving full speed ahead into a new era. "Just yesterday the big issue was oil, but climate change is moving things in a different direction," he says. Weinhold believes that we are currently on the threshold of a new electric age. Electricity is increasingly becoming an all-encompassing energy carrier. This is good for the climate, because electricity can be generated ecologically and transmitted very efficiently. ■ Florian Martini

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can for the first time record in detail where and how much electricity is being used and fed into the grid." The advantage is obvious: If electricity consumption is precisely recorded, flexible rates can be used to match consumption to supply. This lowers electric bills and CO₂ emissions. In contrast, at present if more electricity is being consumed than was forecast, the production of electricity must be increased. Shedding some light on the distribution grid isn't the only advantage associated with smart meters. "Smart meters heighten energy use awareness and help to better control it," adds Günther. "In addition, they are a prerequisite for actively participating in electricity markets."

mitted and how can we obtain useful information from it," she explains. The interfaces will connect both private and commercial electricity customers within model regions to an electronic marketplace and link them to energy traders, distribution grid operators, and other participants. The project is scheduled for completion in 2012. Rusitschka believes that projects like E-DeMa will boost the smart grid's prospects. "The technology is available and it works," she says. "The first larger-scale smart grid solutions could become reality by 2015."

Virtual Networks. Another component of the smart grid is the "virtual power plant" (see p. 40). Here, the idea is that small energy pro-

