Technology Review PUBLISHED BY MIT

January/February 2009

Lifeline for Renewable Power

Without a radically expanded and smarter electrical grid, wind and solar will remain niche power sources.

By David Talbot

Push through a bulletproof revolving door in a nondescript building in a dreary patch of the former East Berlin and you enter the control center for Vattenfall Europe Transmission, the company that controls northeastern Germany's electrical grid. A monitor displaying a diagram of that grid takes up most of one wall. A series of smaller screens show the real-time output of regional wind turbines and the output that had been predicted the previous day. Germany is the world's largest user of wind energy, with enough turbines to produce 22,250 megawatts of electricity. That's roughly the equivalent of the output from 22 coal plants--enough to meet about 6 percent of Germany's needs. And because Vattenfall's service area produces 41 percent of German wind energy, the control room is a critical proving ground for the grid's ability to handle renewable power.

Like all electrical grids, the one that Vattenfall manages must continually match power production to demand from homes, offices, and factories. The challenge is to maintain a stable power supply while incorporating electricity from a source as erratic as wind. If there's too little wind-generated power, the company's engineers might have to start up fossil-fueled power plants on short notice, an inefficient process. If there's too much, it could overload the system, causing blackouts or forcing plants to shut down.

The engineers have few options, however. The grid has a limited ability to shunt extra power to other regions, and it has no energy-storage capacity beyond a handful of small facilities that pump water into uphill reservoirs and then release it through turbines during periods of peak demand. So each morning, as offices and factories switch their power on, the engineers must use wind predictions to help decide how much electricity conventional plants should start producing.

But those predictions are far from perfect. As more and more wind turbines pop up in Germany, so do overloads and shortages caused by unexpected changes in wind level. In 2007, Vattenfall's engineers had to scrap their daily scheduling plans roughly every other day to reconfigure electricity supplies on the fly; in early 2008, such changes became necessary every day. Power plants had to cycle on and off inefficiently, and the company had to make emergency electricity purchases at high prices. Days of very high wind and low demand even forced the Vattenfall workers to quickly shut the wind farms down.

Vattenfall's problems are a preview of the immense challenges ahead as power from renewable sources, mainly wind and solar, starts to play a bigger role around the world. To make use of this clean energy, we'll need more transmission lines that can transport power from one region to another and connect energy-hungry cities with the remote areas where much of our renewable power is likely to be generated. We'll also need far smarter controls throughout the distribution system--technologies that can store extra electricity from wind farms in the batteries of plug-in hybrid cars, for example, or remotely turn power-hungry appliances on and off as the energy supply rises and falls.

If these grid upgrades don't happen, new renewable-power projects could be stalled, because they would place unacceptable stresses on existing electrical systems. According to a recent study funded by the European Commission, growing electricity production from wind (new facilities slated for the North and Baltic Seas could add another 25,000 megawatts to Germany's grid by 2030) could at times cause massive overloads. In the United States, the North American Electric Reliability Corporation, a nongovernmental organization set up to regulate the industry after a huge 1965 blackout, made a similar warning in November. "We are already operating the system closer to the edge than in the past," says the group's president, Rick Sergel. "We simply do not have the transmission capacity available to properly integrate new renewable resources."

The challenge facing the United States is particularly striking. Whereas Germany already gets 14 percent of its electricity from renewable sources, the United States gets only about 1 percent of its electricity from wind, solar, and geothermal power combined. But more than half the states have set ambitious goals for increasing the use of renewables, and president-elect Barack Obama wants 10 percent of the nation's electricity to come from renewable sources by the end of his first term, rising to 25 percent by 2025. Yet unlike Germany, which has begun planning for new transmission lines and passing new laws meant to accelerate their construction, the United States has no national effort under way to modernize its system. "A failure to improve our grid will be a significant burden for the development of new renewable technologies," says Vinod Khosla, founder of Khosla Ventures, a venture capital firm in Menlo Park, CA, that has invested heavily in energy technologies.

Gridlock

When its construction began in the late 19th century, the U.S. electrical grid was meant to bring the cheapest power to the most people. Over the past century, regional monopolies and government agencies have built power plants--mostly fossil-fueled--as close to population centers as possible. They've also built transmission and distribution networks designed to serve each region's electricity consumers. A patchwork system has developed, and what connections exist between local networks are meant mainly as backstops against power outages. Today, the United States' grid encompasses 164,000 miles of high-voltage transmission lines--those familiar rows of steel towers that carry electricity from power plants to substations--and more than 5,000 local distribution networks. But while its size and complexity have grown immensely, the grid's basic structure has changed little since Thomas Edison switched on a distribution system serving 59 customers in lower Manhattan in 1882. "If Edison would wake up today, and he looked at the grid, he would say, 'That is where I left it,'" says Guido Bartels, general manager of the IBM Global Energy and Utilities Industry group.

While this structure has served remarkably well to deliver cheap power to a broad population, it's not particularly well suited to fluctuating power sources like solar and wind. First of all, the transmission lines aren't in the right places. The gusty plains of the Midwest and the sun-baked deserts of the Southwest--areas that could theoretically provide the entire nation with wind and solar power--are at tail ends of the grid, isolated from the fat arteries that supply power to, say, Chicago or Los Angeles. Second, the grid lacks the storage capacity to handle variability--to turn a source like solar power, which generates no energy at night and little during cloudy days, into a consistent source of electricity. And finally, the grid is, for the most part, a "dumb" one-way system. Consider that when power goes out on your street, the utility probably won't know about it unless you or one of your neighbors picks up the phone. That's not the kind of system that could monitor and manage the fluctuating output of rooftop solar panels or distributed wind turbines.

The U.S. grid's regulatory structure is just as antiquated. While the Federal Energy Regulatory Commission (FERC) can approve utilities' requests for electricity rates and license transmission across state lines, individual states retain control over whether and where major transmission lines actually get built. In the 1990s, many states revised their regulations in an attempt to introduce competition into the energy marketplace. Utilities had to open up their transmission lines to other power producers. One effect of these regulatory moves was that companies had less incentive to invest in the grid than in new power plants, and no one had a clear responsibility for expanding the transmission infrastructure. At the same time, the more open market meant that producers began trying to sell power to regions farther away, placing new burdens on existing connections between networks. The result has been a national transmission shortage.

These problems may now be the biggest obstacle to wider use of renewable energy, which otherwise looks increasingly viable. Researchers at the National Renewable Energy Laboratory in Golden, CO, have concluded that there's no technical or economic reason why the United States couldn't get 20 percent of its electricity from wind turbines by 2030. The researchers calculate, however, that reaching this goal would require a $60 billion investment in 12,650 miles of new transmission lines to plug wind farms into the grid and help balance their output with that of other electricity sources and with consumer demand. The inadequate grid infrastructure "is by far the number one issue with regard to expanding wind," says Steve Specker, president of the Electric Power Research Institute (EPRI) in Palo Alto, CA, the industry's research facility. "It's already starting to restrict some of the potential growth of wind in some parts of the West."

The Midwest Independent Transmission System Operator, which manages the grid in a region covering portions of 15 states from Pennsylvania to Montana, has received hundreds of applications for grid connections from would-be energy developers whose proposed wind projects would collectively generate 67,000 megawatts of power. That's more than 14 times as much wind power as the region produces now, and much more than it could consume on its own; it would represent about 6 percent of total U.S. electricity consumption. But the existing transmission system doesn't have the capacity to get that much electricity to the parts of the country that need it. In many of the states in the region, there's no particular urgency to move things along, since each has all the power it needs. So most of the applications for grid connections are simply waiting in line, some stymied by the lack of infrastructure and others by bureaucratic and regulatory delays.

Lisa Daniels, for example, waited three years for a grid connection for a planned development of 9 to 12 turbines on her land in Kenyon, MN, 60 miles south of Minneapolis. The installation would be capable of producing 18 megawatts of power. Its site--only a mile and a half from a substation--is "bulldozer ready," says Daniels, who is also executive director of a regional nonprofit that aims to encourage local wind projects. "The system should be plug-and-play, but it's not," she says.

Utilities, however, are reluctant to build new transmission capacity until they know that the power output of remote wind and solar farms will justify it. At the same time, renewable-energy investors are reluctant to build new wind or solar farms until they know they can get their power to market. Most often, they choose to wait for new transmission capacity before bothering to make proposals, says Suedeen Kelly, a FERC commissioner. "It is a chicken-and-egg type of thing," she says.

More Intelligence

The windowless laboratory at GE Global Research in Niskayuna, NY, is stocked with kitchen appliances and lined with wall screens like those in the control centers for an electrical grid. In the lab, Juan de Bedout, manager of the Electric Power and Propulsion Systems Laboratory, describes how a "smart grid" could help make renewables practical. Imagine, he says, that the wind speed suddenly drops at a wind farm, or that a cloud bank moves over a photovoltaic installation. Existing transmission control systems--like those at Vattenfall--will detect the drop in supply and order increases in power production from other sources, particularly natural-gas plants, which can be fired up quickly.

But in a smart grid, the controller could send a message down to a regional distribution system, seeking a reduction in demand. Instantly, a signal would go out to meters in the homes or offices of customers who had agreed, in exchange for rate reductions, to let the utility rig some of their appliances to cut power consumption during supply drop-offs. Within seconds, electric water heaters would shut off for a few minutes, and electronic thermostats would be automatically adjusted by two or three degrees. There would be no need to power up the natural-gas plant.

In one of the more advanced pilot projects testing such a system, the Minneapolis-based utility Xcel Energy and several vendors are investing $100 million to install a smart-grid infrastructure in Boulder, CO. These days, a 115-person Xcel crew is out full time, installing two-way electric meters at 50,000 houses. Homeowners are getting software that lets them view and manage their energy consumption on the Web, and some of their appliances are being fitted with switches that will let the utility shut them off remotely during periods of high demand.

Smart-grid technologies could reduce overall electricity consumption by 6 percent and peak demand by as much as 27 percent. The peak-demand reductions alone would save between $175 billion and $332 billion over 20 years, according to the Brattle Group, a consultancy in Cambridge, MA. Not only would lower demand free up transmission capacity, but the capital investment that would otherwise be needed for new conventional power plants could be redirected to renewables. That's because smart-grid technologies would make small installations of wind turbines and photovoltaic panels much more practical. "They will enable much larger amounts of renewables to be integrated on the grid and lower the effective overall system-wide cost of those renewables," says the Brattle Group's Peter Fox-Penner.

In Boulder, for example, Xcel is encouraging consumers to install solar panels on their roofs and banks of batteries in their basements--part of a plan to demonstrate how the variable power produced by thousands or millions of solar roofs could be stored in individual homes and fed into the grid when needed. In recent months, Xcel has even purchased a few plug-in hybrid cars and connected them to the grid, in order to test software that would let the vehicles act as energy-storage devices.

And Xcel is not alone. Startups and large companies alike are perfecting and commercializing solar roofing materials, basement energy-storage devices, batteries for plug-in hybrids, and clever software to optimize electricity use. But just as large-scale renewable-power generation depends on improving the transmission infrastructure, many of these advances are useless without better grid controls. You can't use a plug-in's battery for grid storage if the grid cannot intelligently retrieve power from the car.

The good news is that many utilities have begun installing the requisite meters--ones that intelligently monitor power flow out of a house as well as into it. The question now is how to move beyond the blizzard of pilot projects, install smarter technologies across the grid, and begin integrating more renewable power into the new infrastructure. "The smart-grid vision is nice; we all have our color PowerPoint slides," says Don Von Dollen, who manages intelligent-grid research at EPRI. "I think people kind of get the vision by now. Now it's time to get stuff done."

Vicious Circle

Last summer, former vice president Al Gore began arguing that the country needed to implement an entirely carbon-free electricity system within a decade to avert the danger of global warming. As part of his vision, Gore called for a "unified national smart grid" that would move power generated from renewable sources to cities, increase the efficiency of electricity use, and allow for greater control over renewable resources. He estimated that the grid overhaul would cost $400 billion over 10 years.

Gore's plan doesn't spell out exactly how such a massive project would be executed. "If it's faster to have comprehensive legislation that gets states to work together and gets private capital to flow in, terrific," says Cathy Zoi, CEO of the Alliance for Climate Protection, the nonprofit that Gore founded in Menlo Park, CA, to press for urgent action on climate change. "If it's faster and easier to allocate federal money and do this as a public-works project, that's fine, too. We are not wedded to one policy instrument."

Right now, of course, neither strategy has been adopted. While pilot projects like the one in Boulder are worthwhile as a way to demonstrate new technologies, they've been implemented in hodgepodge fashion, with different utilities deploying different technologies in different states. Transmission projects are advancing incrementally, but they're often complicated by conflicts between the states. "What we have today is this patchwork of rules and regulations that vary by state," says Peter Corsell, CEO of GridPoint, a startup in Arlington, VA, that makes smart-grid software and is participating in the Boulder project. "We are all entrenched in this broken system, and there is no agreement on how to fix it. It's a vicious circle."

Some think that the answer is to give FERC more authority. Today, the agency can overrule states' decisions on where to site transmission lines, but only in regions that the U.S. Department of Energy has designated as critical for the security of the electricity supply. So far, only two such corridors have been designated: one in the mid-Atlantic states and another in the Southwest. Even in those regions, delays continue. Southern California Edison has proposed a major transmission line in the southwest corridor; stretching from outside Los Angeles to near Phoenix, AZ, it would be able to handle power generated by future photovoltaic and solar-thermal power plants. But Arizona rejected the idea, so the utility is preparing to take its plans to FERC.

Others think the solution is a new federal policy that would make the market for renewable power more lucrative, perhaps by regulating carbon dioxide emissions, as the cap-and-trade policy proposed by Obama would do. Under such a policy, wind energy and other carbon-free electricity sources would become much more valuable, providing an incentive for utilities to expand their capacity to handle them *(see "Q&A," p. 28)*. "It could all change very fast," says Will Kaul, vice president for transmission at Great River Energy in Minnesota, who heads a joint transmission planning effort that includes 11 utilities in the Midwest. "If there was a carbon policy, or a national renewable-energy standard, then the scale of wind generation would explode."

As Gore and other environmental experts warn--and as the engineers at Vattenfall would testify--an explosion in the use of renewables will depend heavily on upgrading the grid. That won't come cheap, but the payoff may be worth it. "We should think about this in the same way we think about the role of the federal highway system," says Ernest Moniz, a physics professor at MIT who heads the school's energy research initiative. "It is the key enabler to allow us to modernize our whole electricity production system. And renewables are an especially important beneficiary. There is no technology reason why we cannot move on this aggressively."

David Talbot is *Technology Review*'s Chief correspondent.

Cambridge, MA
Wednesday, May 20, 2009
http://www.mitcio.com/