Cash crop. The fields of west Texas are producing a harvest of electricity, along with cotton.

ENERGY

Renewables Test IQ of the Grid

Everybody agrees that tomorrow's electrical grid must incorporate wind and solar power seamlessly. But solving the reliability issue won't be easy

In the afternoon of 26 February 2008, the winds died down in a stretch of west Texas that's home to thousands of tall wind turbines. Over a span of 3 hours, the turbines' contribution to the state's electricity grid fell by 75%. That 1500-megawatt (MW) drop—equivalent to the output of three midsized coal-burning power plants—coincided with a spike in demand. At 6:30 p.m., the alternating current in the state's transmission lines started to alternate more sluggishly, an ominous signal that the system was approaching collapse.

Fortunately, managers of the state's power network had struck a set of agreements with large industrial customers allowing them to cut off power temporarily in exchange for lower rates. Within 10 minutes, about 1200 MW of load was sliced from the sagging electrical grid, and the system stabilized. Texans were blissfully unaware that the state's grid had just dodged a bullet. But the episode was an unsettling reminder that not all electricity is created equal, and that clean energy harvested from nature can complicate the job of keeping the lights on.

Such episodes could become more common—and disrupt service—if plans for a massive expansion of wind and solar power are realized. Both sources of energy are variable and relatively unpredictable. Those traits will require the electrical grid to become smarter and more agile, so that it doesn't stumble and collapse when the wind stops blowing or clouds obscure the sun.

Calls for a "smart grid" have become routine in Washington, D.C., and President Barack Obama's stimulus package includes $4.5 billion for "smart grid demonstration projects." Utilities, national laboratories, and universities are all gearing up to compete for those funds. One focus is installing "smart meters" in homes that show consumers how much energy they are using. Another involves planning high-capacity transmission lines to bring wind and solar power from the nation's high plains and deserts to its cities, creating an interstate highway for green power.

But the most important piece of the renewable-energy puzzle may be finding a solution to its erratic spikes and dips. "Everyone understands the need for transmission," says Arshad Mansoor, vice president for power delivery and utilization at the Electric Power Research Institute (EPRI) in Palo Alto, California. "Not everyone understands the reliability issue."

Dance partners

The electrical grid demands exquisite balance. At every instant, the supply of electricity throughout the system—thousands of power plants, substations, and transmission lines—must equal demand. If not, wires overheat, voltage drops, and circuit breakers snap open to protect parts of the grid where supply still matches demand.

To keep the system running smoothly, grid managers line up generating capacity ahead of time. Then, as actual demand swells and falls, minute by minute, gas turbines automatically throttle up and down and coal-fired plants deliver more steam to generators. "Utilities have become accustomed to variations in the time frame of minutes to hours," says Loren Toole, an electrical engineer at Los Alamos National Laboratory in New Mexico. But Toole says the current system isn't nimble enough for wind and solar generators, which can produce surges and drops in electricity within a few seconds or minutes.

That variability hasn't caused problems yet for the overall U.S. grid because solar and wind power supply just over 1% of the country's electricity. But many states, including California, New York, and Illinois, have passed laws requiring that at least 20% of their electricity come from renew-

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able sources within a decade or two (see map, below). Congress is drafting a similar requirement for the entire country.

A study that General Electric prepared for the Electricity Reliability Council of Texas shows the impact on the Texas grid of incorporating 15,000 MW of wind power—four times the amount it now receives. About twice a year, the study predicts, grid managers would see the supply of wind-derived electricity fall by 2400 MW—the equivalent of four or five midsized coal plants—in less than 30 minutes. Power from photovoltaic panels, meanwhile, can drop when clouds come over, only to spike back up a few minutes later.

What utilities desperately need, according to industry insiders, is an array of "dance partners"—sources of additional power that can mirror every tricky move from the forces of nature, stepping forward without missing a beat as the winds die down and retreating when the wind picks up. Potential dance partners include equipment for storing large amounts of electricity, bigger transmission networks that allow utilities to draw power from a larger area, and the ability to control demand by turning off appliances in their customers' homes.

Several technologies in a future "smart grid" could help manage this dance. They include sensors that monitor the state of high-voltage transmission lines and react instantly when conditions deteriorate. Such technologies already exist, but deploying them on a large scale will cost billions of dollars.

Bringing more renewables online may also require more sophisticated analysis of the grid's behavior when power comes from thousands of independently controlled solar panels and wind turbines. Marija Ilic, a specialist on electrical power systems at Carnegie Mellon University in Pittsburgh, Pennsylvania, says researchers at universities and national laboratories are leading the way. "Some utilities are just waking up" to the problem, she says.

Utilities also need more accurate predictions of the weather. "If I can't forecast the wind accurately, I have no choice but to start a bunch of [coal- or gas-burning] units" to serve as a reserve in case the wind dies, says David Hawkins of the California Independent System Operator (CAISO), which manages that state's electrical system. "If I have to do that, I've lost all the advantages of the green energy."

CAISO buys forecasts of its wind power from AWS Truewind LLC, one of a handful of companies selling such a service. "They're getting good," says Hawkins. The day-ahead forecasts—which provide hour-by-hour predictions of a wind farm's power production—used to be off by 40% or more, but "now we're getting errors in the low 20s, heading toward 15 to 17%." The forecasts are continually updated, and "within the hour, we can usually nail it," says Hawkins. The National Center for Atmospheric Research in Boulder, Colorado, recently got funding from Xcel Energy to develop an "advanced wind-prediction system."

Storing power underground

The ideal dance partner is hydroelectric power. Dams are giant energy-storage devices, and they can react quickly, releasing exactly enough electricity to balance what the fickle winds deliver. Denmark is able to meet 20% of its electrical demands with wind power, for example, by drawing upon imported hydropower from Norway.

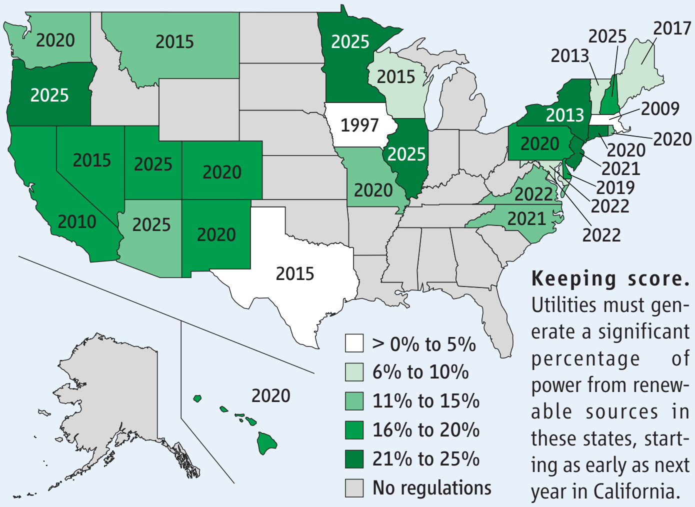
Unfortunately, there isn't nearly enough hydropower to go around. EPRI is promoting what it considers the next best thing, storing power in the form of air pumped into underground caverns under high pressure. "Compressed air is one of the few options we have for real bulk power storage," says EPRI's Dan Rastler. Two such facilities already exist in the United States and Germany. EPRI and a consortium of utilities are planning a more efficient and larger one that would drive a standard gas turbine and generate 400 MW of electricity for up to 10 hours.

Smaller storage projects are also in the works. The Bonneville Power Administration, a federal agency based in Portland, Oregon, already generates enough wind power to satisfy 20% of its peak demand (see graph), and it's working with CAISO to build a facility that stores energy in spinning flywheels. The flywheels are meant to smooth out small fluctuations in wind power, storing excess electricity from brief gusts of wind and releasing it when the wind turbines slow down.

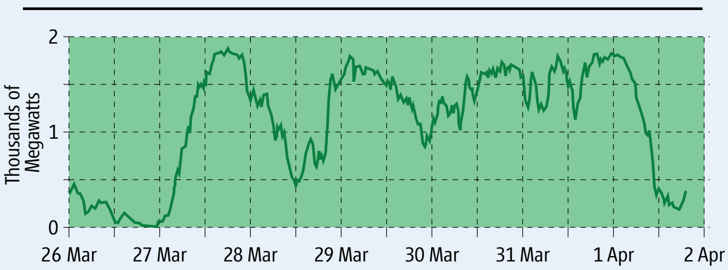
Utilities also have their eye on the batteries of plug-in hybrid vehicles. Those vehicles could become a nightmare for utilities if their owners insist on charging them up after arriving home from work, when power use is at a peak. "My view is, that's no time to charge customers 6 cents per kilowatt-hour; that's a time to charge 6 bucks!" says David Mohler, who's in charge of "smart grid" efforts for Duke Energy, headquartered in Charlotte, North Carolina.

But under some circumstances, those batteries could be a boon to the electric grid. Managers of the grid could pay vehicle owners for the right to control when the charging occurs and eventually the discharging, too. They could fill up the batteries of plug-in hybrids when electricity is

STATES GO GREEN



Keeping score. Utilities must generate a significant percentage of power from renewable sources in these states, starting as early as next year in California.



Unpredictable power. Over the course of a typical week, the amount of wind energy received by the Bonneville Power Administration reached nearly 2000 MW and fell to almost zero.

SOURCES (TOP TO BOTTOM): DEPARTMENT OF ENERGY; SOURCE: BONNEVILLE POWER ADMINISTRATION

Students Energized by Power Engineering

The study of electrical power generation and transmission has long occupied the dusty back corners of U.S. academia. The field was neglected by funders and students alike. When power engineers retired from university faculty positions, they often weren't replaced.

Students avoided the field, in part because deregulated utilities, anxious to cut costs, weren't hiring, says Anjan Bose, a professor of power engineering at Washington State University, Pullman. A National Science Foundation–sponsored workshop in 2007 on the future power-engineering work force called the situation "a national crisis."

With energy back in the headlines, the tide appears to have turned. The evidence is mostly anecdotal because there is no national census of power-engineering students. But engineers at many U.S. universities tell the same story: Students are back, and faculty members are expecting a big increase in funding opportunities as demand grows for a "smart grid."

"Classrooms are full, and we have this very alive group now," says Marija Ilic of Carnegie Mellon University in Pittsburgh, Pennsylvania. At the University of Wisconsin, Madison, says Christopher DeMarco, "we're definitely seeing a greater influx of students at the graduate level." For many years, these programs relied heavily on students from abroad. DeMarco was grateful for those students, but he admits to being "frustrated" by the scarcity of U.S. students. "That's changed dramatically in the last 2 or 3 years," he says.

Empowered. Marija Ilic says students like the idea of improving the grid.

Ilic herself was born in Yugoslavia (in the part that is now Serbia) and studied electrical engineering in Belgrade before receiving a D.Sc. degree from Washington University in St. Louis, Missouri, in 1980. The field itself has changed, she says. Instead of focusing strictly on technical skills, faculty members now encourage students to explore the political and economic context and environmental impacts of power systems. Students also arrive with different expectations. "People are not just thinking about this as doing engineering but as something that's good for mankind," Ilic says.

One clear sign of renewed interest is at the University of Michigan, which abandoned power engineering in the 1970s because of a general lack of interest. "There was not much of a market for it," says Khalil Najafi, chair of the electrical and computer engineering department. Last fall, the department hired Ian Hiskins, an authority on power grid control, and it is about to add another specialist in energy systems. A third faculty position may open up next year, Najafi adds. **–D.E.C.**

abundant in the wee hours of the morning, then draw on that stored-up power in available vehicles to respond to power shortages in the middle of the day.

The two-way communications needed for such a system are part of what is now being called the "smart grid." Such links, allowing utilities to directly control appliances in people's homes, could become one of the most important tools for adapting to variable power from the sun and wind.

Florida Power & Light (FPL) Co. has been doing this for years to handle peak demand. Almost a million customers have signed up for FPL's "On Call" program, which allows the utility to turn off their water heaters, pool pumps, and sometimes air conditioners for short periods of time. FPL communicates with control boxes on those appliances with signals sent directly over power lines. In an emergency, On Call can quickly cut FPL's peak energy load by 4%.

Many utilities are now experimenting with more ambitious versions of this technology. Duke Energy has outfitted the homes of 32 customers in Ohio with an "energy optimization engine" that allows the utility to manage the most energy-hungry home appliances in the home in exchange for cheaper electricity bills. So far, the utility has only used its power to prevent ovens or water heaters in the same neighborhood from turning on at exactly the same time.

The utilities are treading carefully to avoid a backlash from customers who cherish their ability to dry clothes at their convenience. Mohler says utilities could probably use this tool to cut their load by 10% or 20%. "But could we do it without customers noticing? Probably not."

Green freeloaders?

Christopher DeMarco, an electrical engineer at the University of Wisconsin, Madison, is examining a more subtle feature of green power, namely, its reluctance to perform certain unglamorous but essential functions that keep the grid on solid footing. Old-style power plants, for instance, provide some extra "reactive power" that helps keep voltage stable on the grid. Without it, voltage in an AC system tends to sag.

Early versions of wind farms and solar panels did not help to support the voltage. "It costs them money," says EPRI's Stephen Lee. "So independent power producers, including renewable generators, just pump power onto the grid and depend on the transmission company to provide voltage support." That approach may have been okay when renewables were a boutique source of energy. But as their presence grows, grid managers are requiring many of them to provide voltage support.

DeMarco says solar and wind power also do little to cushion the grid from shocks such as a power plant shutting down unexpectedly. Traditional power plants do this naturally, he says, through the sheer physical mass of machinery that is rotating exactly in time with the oscillation of the grid's alternating current. This system "has a very nice stabilizing dynamic effect," says DeMarco. If a factory operator somewhere flips a switch and pulls more power from the grid, DeMarco says, the generator responds instantly. "It will slow down slightly, and what was kinetic energy gets converted into electrical energy going out the wire."

Solar and wind generators could mimic this response, says DeMarco, but it would require them to reduce their output by a few percentage points and have that power poised to respond instantly to shocks on the grid. Without their cooperation, he predicts, "we are going to run into hard limits on how much renewable generation we can live with, without destabilizing the operation of the grid." DeMarco and his fellow researchers are trying to determine just where those "hard limits" lie.

"There is a tendency in some circles to paint renewables as a threat to the grid," says DeMarco, but he thinks the two can work in harmony. "You need to spend a little money to make them compatible with the grid," he explains, "but there's no insurmountable hurdle." **–DAN CHARLES**

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