Building a weather-smart grid

Renewable energy will rule only when wheather data drive the design of a new electric grid

Peter Fairley is a freelance writer in Victoria, B.C., who specializes in energy and the environment.

THE WIND POWER BOOM IN THE PACIFIC NORTHWEST'S COLUMBIA RIVER GORGE IS BOTH A RENEWABLE energy success story and a cautionary tale. Engineers packed the gorge with thousands of wind turbines that power two million to three million homes. The carbon-free energy, however, regularly causes migraines for operators at the Bonneville Power Administration, based in Portland, Ore., who manage the regional electricity grid. Changing weather shifts winds across the broad span of turbines, creating huge power swings. The havoc is multiplied by Mount Hood, which towers over the gorge and divides the prevailing winds like a big boulder in a stream. The wake from the split meanders through the gorge's wind farms, causing output to spike and slump. For Bonneville, it is akin to a big nuclear power plant on a dimmer switch, with power swinging up and down.

Managing the grid is even more dicey in the spring, when power output surges from the Northwest's massive hydroelectric plants. The dams need to operate flat out because the reservoirs behind them are brimming with meltwater. Spilling water over the wall without generating power would waste the potential energy while filling the river with excess air and killing endangered salmon hatching there by "giving them the bends," says Justin Sharp, a Portland-based energy consultant. So Bonneville sometimes shuts down the wind farms, squandering some of *their* clean energy.

Sharp knows this situation well because he helped create it. After earning his Ph.D. in meteorology by studying the region's rich winds, he spent seven years at energy developer Iberdrola Renewables (now Avangrid Renewables) mining that resource with turbines, which currently feed Bonneville's grid. Sharp says developers designed the wind farms for maximum annual output at lowest cost, and Bonneville beefed up transmission lines to carry that output to market. But everyone, he adds, ignored the weather and climate variability. "Did we assess that variability when we were thinking about building those wind farms? No. Do we assess it now? No. Does it have an impact on the system and its ability to manage lots of wind? Absolutely. A huge amount."

The same story is repeated across the U.S. Experts such as Sharp peer ahead to a day of reckoning for states, cities and businesses planning to switch to carbon-free electricity. If builders continue to ignore weather-driven variability, future grids will become increasingly precarious. "We're trying to ram the square peg of renewables into the round hole of the existing electric system, and I think we're heading for a train wreck," Sharp says.

What is needed is weather-smart grid design, directed by meteorology and built on long-distance transmission lines that can manage the weather's inconsistencies. Such a system could ship gobs of renewable power across North America to link supply with demand, whatever the weather throws at it—allowing, for example, surplus wind in the Columbia River Gorge to help Minneapolis keep humming when Midwestern winds stall, and vice versa. "We haven't done that yet," says Charlie Smith, executive director of Energy Systems Integration Group, an industry association dedicated to managing variable power generation.

TAMING MONSTERS

TO BE FAIR, weather has always informed grid design but only to a crude degree, says Aaron Bloom, who manages the Grid Systems Analysis Group for the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) in Golden, Colo. Heat waves and cold snaps produce the peak strain on a region's grid. Typical planning boils down to ensuring the system can deliver during those hairiest hours of the most extreme weather days. But the rapid scale-up of wind and solar power plants is forcing planners to greatly boost the grid's weather smarts, Bloom says.

IN BRIEF

Wind and solar power will not become the major energy sources until a nationwide transmission grid is designed based on local, daily weather variations.

Models that use detailed weather data can optimize the siting of renewable energy sources and direct-current power lines to connect them.

One model raises renewables to 67 percent of the U.S. electricity supply. But resistance by states and power firms to long DC lines has stifled weather-smart grids.

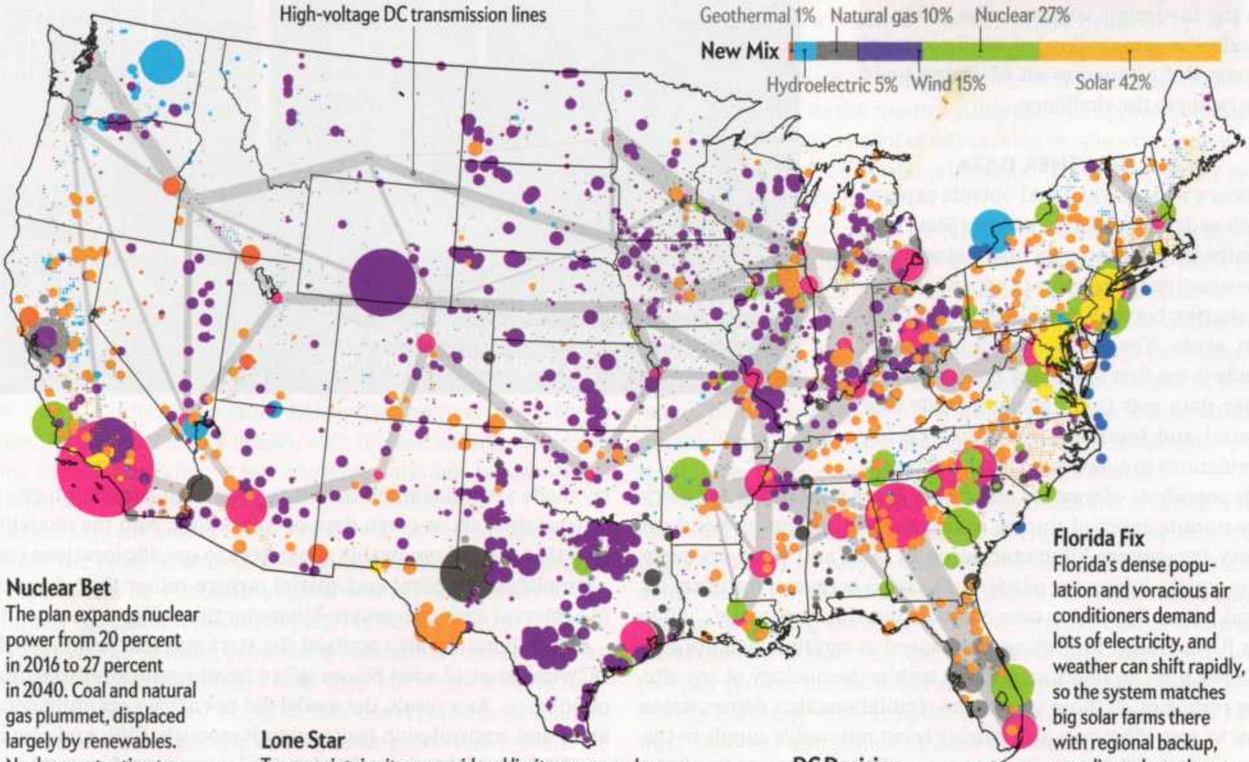
PRECEDING PAGES: GALLERY STOCK

Power Makeover

Radically redesigning the U.S. power system could boost renewable electricity to more than 67 percent of supply by 2040 and eliminate coal plants. The configuration here would emit 89 percent less greenhouse gas than the 2016 system and trim electric bills by 10 percent. The key is using detailed data about how weather changes in every three-by-three-kilometer square of the country every five minutes, year-round, to determine which power plants to build where (*dots*) and how to most efficiently connect regions with direct-current transmission lines (*gray*). This plan, by Vibrant Clean Energy, uses more widely distributed plants than today, so they can back up one another as weather changes nationwide.

Idealized Power Plan for 2040
Each dot represents one type of local power source. Each dot size below represents 1,000 megawatts. On the map, larger dots are proportionally more; smaller are less.

- Storage
- Natural Gas Combined Cycle
- Natural Gas Combustion Turbine
- Rooftop Solar
- Nuclear
- Hydropower
- Offshore Wind
- Geothermal
- Onshore Wind
- Utility-Scale Solar



Nuclear Bet
The plan expands nuclear power from 20 percent in 2016 to 27 percent in 2040. Coal and natural gas plummet, displaced largely by renewables. Nuclear cost estimates are optimistic; if they rise instead, the share would decrease, filled mostly by natural gas.

Lone Star
Texas maintains its own grid and limits power exchanges with neighbors to avoid interference from federal regulators, so it is barely connected here. This simulation also leaves out Canada and Mexico, but a weather-smart grid that maximizes reliability and minimizes cost would crisscross North America.

DC Decision
The extensive grid overhaul requires many long, DC power lines, but only a few exist today.

Florida Fix
Florida's dense population and voracious air conditioners demand lots of electricity, and weather can shift rapidly, so the system matches big solar farms there with regional backup, coordinated over huge DC lines. Battery storage helps to buffer variable solar and wind output and spikes in demand.

Unlike conventional coal, natural gas and nuclear generators, wind turbines and solar panels strongly react to the weather, adding a big variable that changes every day of the year.

Texas and California illustrate the challenge. Texas leads the U.S. in wind capacity, with more than 20 gigawatts installed. But the prevailing winds blow hardest at night, dumping an energy surplus on the grid, thereby forcing utilities to actually pay big customers to take it. That sounds crazy, but it can be less costly than turning the wind systems off and wasting the energy.

California has ample wind and leads the nation in solar power plants and photovoltaic rooftops. The solar collectors raise an electrical tsunami every morning when the sun comes up—sometimes more than the grid can absorb—and then give out in the early evening when consumers still demand plenty of power. California has little recourse. "They're a north-south state, so the sun rises and sets at much the same time on every solar panel," says Mark Ahlstrom, vice president of renewable energy policy for NextEra Energy Resources, a project development company focused on renewables. Extreme weather, meanwhile, disrupted both states' wind power supplies three winters ago. An unusually stable high-pressure ridge over the West Coast cut winds to record lows for several months.

States often get little help from the rest of the country because the grid across the U.S. is divided into three big, isolated regions. This balkanization means each region must manage weather variability on its own. The Eastern Interconnection and Western Interconnection—the two alternating-current (AC) power grids that serve most of the U.S. and Canada and a bit of Mexico—exchange almost no power. And they exchange even less with Texas, which operates its own AC grid.

Consumers are unaware of the mounting drama renewables

Map by Christopher Clack, Vibrant Clean Energy may cause because giant wind turbines and solar arrays supply only 7.6 percent of U.S. electricity, combined. Grid operators still have thousands of conventional power plants they can ramp up and down to balance these gyrating sources. But renewables' share is headed skyward. California has mandated that it will reach 50 percent by 2030 (not including large hydropower plants); Hawaii intends to hit 100 percent as soon as 2040. Only a few utilities and transmission operators are trying to design weather-wise grids to handle the coming flood of wind and solar power. But a growing set of design tools are rising to the challenge.

WIND FARMS in Washington State could send electricity thousands of miles eastward if the U.S. power grid were upgraded with DC lines.

INGA SPENCE Getty Images

BIG WEATHER DATA

BLOOM'S TEAM AT NREL, and outside experts such as James McCalley of Iowa State University, is wrapping up a major study that is evaluating the benefits of expanded power sharing between the Eastern and Western grids. The Interconnections Seam Study is the first to employ new wind and solar data sets that have extremely fine spatial and temporal resolution, taking simulations to a new level. NREL's data provide snapshots of weather and power flows nationwide for every five-minute interval during an entire year, mapping wind on every two-square-kilometer patch of land and solar on every four-square-kilometer patch. Such detail is crucial for charting wind power variability over complex terrain, such as the Columbia River Gorge. Projecting wind speed at multiple heights also enables NREL to select an optimal turbine technology at any site. The results of all those smarts are simulations that demonstrate how to cost-effectively and reliably boost renewable supply in the continental U.S. (minus Texas) to more than 54 percent by 2040—far greater than today's level.

The simulations erase the Eastern-Western power divide by knitting the two grids together along their common border with several big direct-current power lines or by crisscrossing them with a network of longer DC lines from the Pacific Coast to the Midwest, plus a main line from Louisiana to Florida. DC wires are used because they lose much less power than AC wires do over long distances, making faraway delivery economically viable. NREL's models determined how much power the lines should be able to carry and where to place new generators to take advantage of the bolstered transmission system.

The models recognize various opportunities for weather-smart optimization, such as installing a greater range of wind turbine types and solar panels in more widespread locations rather than bunching them in a few exceptionally windy or sunny regions, where they tend to get located today. The result is very likely more consistent renewable energy requiring fewer reserves by conventional power plants, according to NREL energy modeler Greg Brinkman. "Natural diversity gets baked in," he says.

NREL's modeling, for all its sophistication, also shows the enduring challenge of weather-smart design. For example, McCalley made several simplifications to keep each simulation run to a "tractable" six or seven days of computing. And the modeling step that assigns renewable generators to specific locations used a simplified temporal and spatial picture rather than five-minute-interval and four-square-kilometer precision.

The laboratory also prefixed the start and end points for the DC wires to avoid what Bloom calls a "mathematically intractable" calculation. As a result, the model did not always optimize generators and transmission routes simultaneously. Still, preliminary results from NREL show that long DC wires would save $3.8 billion annually by, for example, slashing coal and gas consumption, paying for themselves more than three times over. But each kilometer of DC transmission could deliver even greater savings—and deeper cuts in carbon emissions—with a fully optimized layout.

Recent modeling to redesign Europe's grid for the robust renewable energy expected there by 2040 confirms that NREL's simulation shortcuts most likely leave some renewable energy potential on the table. The European Network of Transmission System Operators for Electricity, a Brussels-based consortium, added enough wind, solar and other renewable generators to a 2030 grid model to boost total renewables to 75 percent. Its experts then produced a conceptual 2040 grid by expanding interconnections between countries to alleviate bottlenecks in seasonal power flow. Finally, they redistributed the same generators to take better advantage of the redesigned grid. This iterative process of optimization boosted renewable energy to more than 80 percent in the 2040 design.

BETTER ALGORITHMS

ONE INDEPENDENT RESEARCHER claims he can merge all these modeling techniques together to squeeze even more value from the weather data. Christopher Clack, CEO of Vibrant Clean Energy, a grid-modeling and power-forecasting firm in Boulder, Colo., developed his advanced weather-driven grid algorithms during a four-year stint at the National Oceanic and Atmospheric Administration. Then, in 2016, he launched his proprietary, commercial software, called WIS:dom.

WIS:dom uses the same kind of high-resolution weather data that NREL does but in a different way, Clack claims, and thus creates more opportunities for renewable energy. His recent analysis of the big U.S. grids led to a system in which renewables would provide 62 percent of generation by 2040, which is 20 percent more than NREL's most recent projection. The simulated grid also delivers power 10 percent cheaper than today's. Clack says his model could push renewables to more than 67 percent, long before 2040, if the savings were plowed back into accelerated investment in the transmission system.

Clack argues that WIS:dom squeezes more intelligence from weather data by simultaneously optimizing power plants and transmission—notably the long DC lines—rather than fixing the lines ahead of time, as NREL had to do. The model also taps into how renewable generators across the country tend to fluctuate relative to one another hour by hour, better balancing wind and solar power in distant places. For example, WIS:dom can tell when Texas's rising nighttime wind energy can offset lagging offshore winds on the East Coast, which blow more during the day. "All the different regions help other regions at different times," Clack says. NREL's model, with its restrictions, may miss some of this, McCalley acknowledges, although he questions whether the simplifications make much difference.

Clack says his model takes "only" two days of computing to spit out the more optimized grid plans. Experts say his integrated models may be a breakthrough in weather-smart design. "He definitely has taken it to a higher level of fidelity," Ahlstrom says.

What WIS:dom lacks, however, is validation. Experts such as Ahlstrom, Bloom and others wish they knew more about how Clack's proprietary tool works so they could confirm its reliability. "Chris is a smart guy. He's doing some great stuff. I just don't know what his special sauce is," Bloom says. It seems unlikely that Clack will be sharing it. He is, after all, selling outputs from his software to energy companies, including advice on where regional grid operators and entrepreneurial transmission builders should target billions of dollars in investments.

POLITICAL INHIBITORS

ENERGY DEVELOPERS such as Sharp and Smith are trying to encourage grid companies and scientific organizations such as the American Meteorological Society to emphasize weather-smart planning. They also say political and industry leaders must campaign for DC transmission to overcome resistance to it. State renewable energy mandates are prompting grid operators to build AC lines to reach wind and solar resources. But only a handful of firms are trying to build the long DC lines needed to exchange renewable energy among regions, as Europe, China and others are doing.

Not-in-my-backyard opposition to power lines is part of the problem. Another is a shift in utility investments toward "nonwire" solutions for grid issues, such as battery storage. Big, expensive batteries located where power is needed can accept surplus power—such as from the Texas night winds—and save it for a few dark, windless days. But batteries may do little to help regions endure extreme events such as the 2015 Western wind drought. "It's not like you're going to be able to take all of that power that your [solar] is generating during the summer and put it into a battery for the winter," Sharp says.

Regional turf wars may be an even bigger barrier to long DC interconnections. Local and state officials have often blocked large power lines carrying cheap energy from afar to protect in-state generators. The resistance to big DC has been a bitter lesson for Dale Osborn, who led the team that designed the NREL study's DC network. Osborn was the U.S. power industry's leading advocate for DC-enhanced grids until he retired last year from the Midcontinent Independent System Operator, which operates the power lines and a wholesale power market shared by 15 U.S. states and Manitoba. As NREL's analysis shows, a system that can trade electricity from Washington State to Florida requires fewer power plants across the country. Although this approach reduces overall cost, "there are a lot of self-serving people who don't want lower-cost generation," Osborn laments. "They want higher prices for *their* generation."

Clack says high-voltage DC (HVDC) prospects look so dim in the U.S. that clients typically ask him to exclude it from the studies he performs for them, forcing WIS:dom to make do with shorter, more numerous AC lines. "The long-distance HVDC is turned off because most believe it will not happen," Clack says—at least not for the foreseeable future. And unfortunately, he notes, when he turns DC off yet keeps costs constant, roughly half of the carbon dioxide emissions reductions that result from fewer conventional power plants vanish.

The federal government could help break the gridlock. President Barack Obama's secretary of energy, Ernest Moniz, exercised untested statutory authority to take land through eminent domain for a DC line deemed to be of national importance. That undertaking, designed to move surplus wind power from Oklahoma to markets in the mid-South and Southeast, was recently put on the back burner by its proponent, Clean Line Energy Partners, while it fights for several projects in the Midwest that were also stalled by local and state opposition.

Similar transmission activism under President Donald Trump is less likely. Secretary of Energy Rick Perry is focused on protecting coal-fired power plants, arguing that expanding their on-site coal reserves makes the grid more "resilient" against extreme weather. But experts point out that coal piles can freeze during cold snaps and flood during tropical storms, forcing the plants to shut down. The same weather often brings atmospheric pressure gradients that spin wind turbines and clear skies that maximize solar output. As Sharp observes, "There are places within the country with very robust renewable energy during extreme weather."

If only there was a weather-smart grid to deliver it. ■

MORE TO EXPLORE

Transmission Upgrades & Expansion: Keys to Meeting Large Customer Demand for Renewable Energy. David Gardiner and Associates. Wind Energy Foundation, January 2018.

National Renewable Energy Laboratory's Interconnections Seam Study: **www.nrel.gov/analysis/seams.html**

FROM OUR ARCHIVES

How to Build the Supergrid. Matthew L. Wald; November 2010.

scientificamerican.com/magazine/sa