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The 21st Century Grid

Can we fix the infrastructure that powers our lives?

By Joel Achenbach

We are creatures of the grid. We are embedded in it and empowered by it. The sun used to govern our lives, but now, thanks to the grid, darkness falls at our convenience. During the Depression, when power lines first electrified rural America, a farmer in Tennessee rose in church one Sunday and said—power companies love this story—"The greatest thing on earth is to have the love of God in your heart, and the next greatest thing is to have electricity in your house." He was talking about a few lightbulbs and maybe a radio. He had no idea.

Juice from the grid now penetrates every corner of our lives, and we pay no more attention to it than to the oxygen in the air. Until something goes wrong, that is, and we're suddenly in the dark, fumbling for flashlights and candles, worrying about the frozen food in what used to be called (in pre-grid days) the icebox. Or until the batteries run dry in our laptops or smart phones, and we find ourselves scouring the dusty corners of airports for an outlet, desperate for the magical power of electrons.

The grid is wondrous. And yet—in part because we've paid so little attention to it, engineers tell us—it's not the grid we need for the 21st century. It's too old. It's reliable but not reliable enough, especially in the United States, especially for our mushrooming population of finicky digital devices. Blackouts, brownouts, and other power outs cost Americans an estimated $80 billion a year. And at the same time that it needs to become more reliable, the grid needs dramatic upgrading to handle a different kind of power, a greener kind. That means, among other things, more transmission lines to carry wind power and solar power from remote places to big cities.

Most important, the grid must get smarter. The precise definition of "smart" varies from one engineer to the next. The gist is that a smart grid would be more automated and more "self-healing," and so less prone to failure. It would be more tolerant of small-scale, variable power sources such as solar panels and wind turbines, in part because it would even out fluctuations by storing energy—in the batteries of electric cars, according to one speculative vision of the future, or perhaps in giant caverns filled with compressed air.

But the first thing a smart grid will do, if we let it, is turn us into savvier consumers of electricity. We'll become aware of how much we're consuming and cut back, especially at moments of peak demand, when electricity costs most to produce. That will save us and the utilities money—and incidentally reduce pollution. In a way, we'll stop being mere passive consumers of electrons. In the 21st century we'll become active participants in the management of this vast and seemingly unknowable network that makes our civilization possible.

So maybe it's time we got to know it.

There are grids today on six continents, and someday Europe's may reach across the Mediterranean into Africa to carry solar power from the Sahara to Scandinavia. In Canada and the U.S. the grid carries a million megawatts across tens of millions of miles of wire. It has been called the world's biggest machine. The National Academy of Engineering calls it the greatest engineering achievement of the last century.

Thomas Edison, already famous for his lightbulb, organized the birth of the grid in 1881, digging up lower Manhattan to lay down copper wires inside brick tunnels. He constructed a power plant, the Pearl Street Station, in the shadow of the Brooklyn Bridge. On September 4, 1882, in the office of tycoon J. P. Morgan, Edison threw a switch. Hundreds of his bulbs lit up Drexel, Morgan & Co. and other offices nearby.

Edison was heavily invested in direct current, which worked well in his bulbs and which at the time was low voltage. Alternating current, he argued colorfully, was more appropriate to executing criminals. (He had a circus elephant electrocuted to prove his point.) The argument was misleading: AC, in which the electrons don't stream in one direction but oscillate back and forth at a given frequency, isn't intrinsically more dangerous than DC. High voltage is what's dangerous—but it's also what allows power to be transmitted hundreds of miles without excessive loss. AC won out over DC largely because it can easily be stepped up with transformers, transmitted, then stepped down again to a safer household voltage of 110 or 220. By the 1890s AC lines were running from the new Niagara Falls generating station to Buffalo, some 20 miles away. These days, ironically, high-voltage DC is sometimes preferred for very long distances; it's harder to produce than AC, but it loses even less power.

It took decades for electricity to expand from factories and mansions into the homes of the middle class. In 1920 electricity still accounted for less than 10 percent of the U.S. energy supply. But inexorably it infiltrated everyday life. Unlike coal, oil, or gas, electricity is clean at the point of use. There is no noise, except perhaps a faint hum, no odor, and no soot on the walls. When you switch on an electric lamp, you don't think of the huge, sprawling power plant that's generating the electricity (noisily, odoriferously, sootily) many miles away. Refrigerators replaced iceboxes, air conditioners replaced heat prostration, and in 1956 the electric can opener completed our emergence from the dark ages. Today about 40 percent of the energy we use goes into making electricity.

At first, utilities were local operations that ran the generating plant and the distribution. A patchwork of mini-grids formed across the U.S. In time the utilities realized they could improve reliability and achieve economies of scale by linking their transmission networks. After the massive Northeast blackout of 1965, much of the control of the grid shifted to regional operators spanning many states. Yet today there is still no single grid in the U.S.; there are three nearly independent ones—the Eastern, Western, and Texas Interconnections.

They function with antiquated technology. The parts of the grid you come into contact with are symptomatic. How does the power company measure your electricity usage? With a meter reader—a human being who goes to your home or business and reads the dials on a meter. How does the power company learn that you've lost power? When you call on the phone. In general, utilities don't have enough instantaneous information on the flow of current through their lines—many of those lines don't carry any data—and people and slow mechanical switches are too involved in controlling that flow.

"The electrical grid is still basically 1960s technology," says physicist Phillip F. Schewe, author of *The Grid*. "The Internet has passed it by. The meter on the side of your house is 1920s technology." Sometimes that quaintness becomes a problem. On the grid these days, things can go bad very fast.

When you flip a light switch, the electricity that zips into the bulb was created just a fraction of a second earlier, many miles away. Where it was made, you can't know, because hundreds of power plants spread over many states are all pouring their output into the same communal grid. Electricity can't be stored on a large scale with today's technology; it has to be used instantly. At each instant there has to be a precise balance between generation and demand over the whole grid. In control rooms around the grid, engineers constantly monitor the flow of electricity, trying to keep voltage and frequency steady and to avoid surges that could damage both their customers' equipment and their own.

When I flip a switch at my house in Washington, D.C., I'm dipping into a giant pool of electricity called the PJM Interconnection. PJM is one of several regional operators that make up the Eastern grid; it covers the District of Columbia and 13 states, from the Mississippi River east to New Jersey and all the way down to the Outer Banks of North Carolina. It's an electricity market that keeps supply and demand almost perfectly matched—every day, every minute, every fraction of a second—among hundreds of producers and distributors and 51 million people, via 56,350 miles of high-voltage transmission lines.

One of PJM's new control centers is an hour north of Philadelphia. Last February I went to visit it with Ray E. Dotter, a company spokesman. Along the way Dotter identified the power lines we passed under. There was a pair of 500-kilovolt lines linking the Limerick nuclear plant with the Whitpain substation. Then a 230-kilovolt line. Then another. Burying the ungainly lines is prohibitively expensive except in dense cities. "There's a need to build new lines," Dotter said. "But no matter where you propose them, people don't want them."

Dotter pulled off the turnpike in the middle of nowhere. A communications tower poked above the treetops. We drove onto a compound surrounded by a security fence. Soon we were in the bunker, built by AT&T during the Cold War to withstand anything but a direct nuclear hit and recently purchased by PJM to serve as its new nerve center.

In the windowless control room, dominated by a curved wall of 36 computer screens, dispatch general manager Mike Bryson explained what I was seeing. A dynamic map on one of the screens showed the PJM part of the grid. Arrows represented major transmission lines, each with a number showing how much juice was on the line at that moment. Most of the arrows pointed west to east: In the eastern U.S. electricity flows from major power plants in the heartland toward huge clusters of consumers along the eastern seaboard. At that moment PJM lines were carrying 88,187 megawatts. "Today is a mild winter day —I don't think we'll have over 90,000," Bryson said.

The computers take data from 65,000 points on the system, he explained. They track the thermal condition of the wires; too much power flowing through a line can overheat it, causing the line to expand and sag dangerously. PJM engineers try to keep the current alternating at a frequency of precisely 60 hertz. As demand increases, the frequency drops, and if it drops below 59.95 hertz, PJM sends a message to power plants asking for more output. If the frequency increases above 60.05 hertz, they ask the plants to reduce output. It sounds simple, but keeping your balance on a tightrope might sound simple too until you try it. In the case of the grid, small events not under the control of the operators can quickly knock down the whole system.

Which brings us to August 14, 2003. Most of PJM's network escaped the disaster, which started near Cleveland. The day was hot; the air conditioners were humming. Shortly after 1 p.m EDT, grid operators at First Energy, the regional utility, called power plants to plead for more volts. At 1:36 p.m. on the shore of Lake Erie, a power station whose operator had just promised to "push it to my max max" responded by crashing. Electricity surged into northern Ohio from elsewhere to take up the slack.

At 3:05 a 345-kilovolt transmission line near the town of Walton Hills picked that moment to short out on a tree that hadn't been trimmed. That failure diverted electricity onto other lines, overloading and overheating them. One by one, like firecrackers, those lines sagged, touched trees, and short-circuited.

Grid operators have a term for this: "cascading failures." The First Energy operators couldn't see the cascade coming because an alarm system had also failed. At 4:06 a final line failure sent the cascade to the East Coast. With no place to park their electricity, 265 power plants shut down. The largest blackout in North American history descended on 50 million people in eight states and Ontario.

At the Consolidated Edison control center in lower Manhattan, operators remember that afternoon well. Normally the power load there dips gradually, minute by minute, as workers in the city turn off their lights and computers and head home. Instead, at 4? p.m. lights went out in the control room itself. The operators thought: 9/11. Then the phone rang, and it was the New York Stock Exchange. "What's going on?" someone asked. The operators knew at once that the outage was citywide.

There was no stock trading then, no banking, and no manufacturing; restaurants closed, workers were idled, and everyone just sat on the stoops of their apartment buildings. It took a day and a half to get power back, one feeder and substation at a time. The blackout cost six billion dollars. It also alarmed Pentagon and Homeland Security officials. They fear the grid is indeed vulnerable to terrorist attack, not just to untrimmed trees.

The blackout and global warming have provided a strong impetus for grid reform. The federal government is spending money on the grid—the economic-stimulus package allocated $4.5 billion to smart grid projects and another six billion dollars or so to new transmission lines. Nearly all the major utilities have smart grid efforts of their own.

A smarter grid would help prevent blackouts in two ways. Faster, more detailed feedback on the status of the grid would help operators stay ahead of a failure cascade. Supply and demand would also be easier to balance, because controllers would be able to tinker with both. "The way we designed and built the power system over the last hundred years—basically the way Edison and Westinghouse designed it—we create the supply side," says Steve Hauser of the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) near Boulder, Colorado. "We do very little to control demand."

Working with the NREL, Xcel Energy has brought smart grid technology to Boulder. The first step is the installation of smart meters that transmit data over fiber-optic cable (it could also be done wirelessly) to the power company. Those meters allow consumers to see what electricity really costs at different times of day; it costs more to generate during times of peak load, because the utilities have to crank up auxiliary generators that aren't as efficient as the huge ones they run 24/7.

When consumers are given a price difference, they can choose to use less of the expensive electricity and more of the cheap kind. They can run clothes dryers and dishwashers at night, for instance. The next step is to let grid operators choose. Instead of only increasing electricity supply to meet demand, the operators could also reduce demand. On sweltering summer days the smart grid could automatically turn up thermostats and refrigerators a bit—with the prior agreement of the homeowners of course.

"Demand management" saves energy, but it could also help the grid handle renewable energy sources. One of the biggest problems with renewables like solar and wind power is that they're intermittent. They're not always available when demand peaks. Reducing the peak alleviates that problem. You can even imagine programming smart appliances to operate only when solar or wind power is available.

Some countries, such as Italy and Sweden, are ahead of the U.S. in upgrading their electrical intelligence. The Boulder project went online earlier this year, but only about 10 percent of U.S.customers have even the most primitive of smart meters, Hauser estimates.

"It's expensive," he says. "Utilities are used to spending 40 bucks on an old mechanical meter that's got spinning dials. A smart meter with a software chip, plus the wireless communication, might cost $200—five times as much. For utilities, that's huge." The Boulder project has cost Xcel Energy nearly three times what it expected. Earlier this year the utility raised rates to try to recoup some of those costs.

Although everyone acknowledges the need for a better, smarter, cleaner grid, the paramount goal of the utility industry continues to be cheap electricity. In the U.S. about half of it comes from burning coal. Coal-powered generators produce a third of the mercury emissions in America, a third of our smog, two-thirds of our sulfur dioxide, and nearly a third of our planet-warming carbon dioxide—around 2.5 billion metric tons a year, by the most recent estimate.

Not counting hydroelectric plants, only about 3 percent of American electricity comes from renewable energy. The main reason is that coal-fired electricity costs a few cents a kilowatt-hour, and renewables cost substantially more. Generally they're competitive only with the help of government regulations or tax incentives. Utility executives are a conservative bunch. Their job is to keep the lights on. Radical change makes them nervous; things they can't control, such as government policies, make them nervous. "They tend to like stable environments," says Ted Craver, head of Edison International, a utility conglomerate, "because they tend to make very large capital investments and eat that cooking for 30 or 40 or 50 years."

So windmills worry them. A utility executive might look at one and think: What if the wind doesn't blow? Or look at solar panels and think: What if it gets cloudy? A smart grid alone can't solve the intermittence problem. The ultimate solution is finding ways to store large amounts of electricity for a rainy, windless day.

Actually the U.S. can already store around 2 percent of its summer power output—and Europe even more—behind hydroelectric dams. At night, when electricity is cheaper, some utilities use it to pump water back uphill into their reservoirs, essentially storing electricity for the next day. A small power plant in Alabama does something similar; it pumps air into an underground cavern at night, compressing it to more than a thousand pounds per square inch. During the day the compressed air comes rushing out and spins a turbine. In the past year the Department of Energy has awarded stimulus money to several utilities for compressed-air projects. One project in Iowa would use wind energy to compress the air.

Another way to store electricity, of course, is in batteries. For the moment, it makes sense on a large scale only in extreme situations. For example, the remote city of Fairbanks, Alaska, relies on a huge nickel-cadmium, emergency-backup battery. It's the size of a football field.

Lithium-ion batteries have more long-term potential—especially the ones in electric or plug-in-hybrid cars. PJM is already paying researchers at the University of Delaware $200 a month to store juice in three electric Toyotas as a test of the idea. The cars draw energy from the grid when they're charging, but when PJM needs electricity to keep its frequency stable, the cars are plugged in to give some back. Many thousands of cars, the researchers say, could someday function as a kind of collective battery for the entire grid. They would draw electricity when wind and solar plants are generating, and then feed some back when the wind dies down or night falls or the sun goes behind clouds. The Boulder smart grid is designed to allow such two-way flow.

To accommodate green energy, the grid needs not only more storage but more high-voltage power lines. There aren't enough running to the places where it's easy to generate the energy. To connect wind farms in Kern County with the Los Angeles area, Southern California Edison, a subsidiary of Edison International, is building 250 miles of them, known as the Tehachapi Renewable Transmission Project. A California law requires utilities to generate at least 20 percent of their electricity from renewable sources as of this year.

Green energy would also get a boost if there were more and bigger connections between the three quasi-independent grids in the U.S. West Texas is a Saudi Arabia of wind, but the Texas Interconnection by itself can't handle all that energy. A proposed project called the Tres Amigas Superstation would allow Texas wind—and Arizona sun—to supply Chicago or Los Angeles. Near Clovis, New Mexico, where the three interconnections already nearly touch, they would be joined together by a loop of five-gigawatt-capacity superconducting cable. The three grids would become, in effect, one single grid, national and almost rational.

Studying the map of the grid in the PJM control room, I noticed unfamiliar place-names: Amos, Pruntytown, Matt Funk, Sporn. Washington, D.C., was not labeled; Mike Bryson suggested it was somewhere near a substation called Waugh Chapel. One of the largest generating stations on the map, he added helpfully, was the Gavin plant, which at that moment was cranking out 2,633 megawatts.

Where's Gavin? I asked.

"West Virginia or Kentucky somewhere," Bryson said.

It's actually in southern Ohio. The grid is a kind of parallel world that props up our familiar one but doesn't map onto it perfectly. It's a human construction that has grown organically, like a city or a government—what technical people call a kludge. A kludge is an awkward, inelegant contraption that somehow works. The U.S. grid works well by most measures, most of the time; electricity is abundant and cheap.

It's just that our measures have changed, and so the grid must too. The power industry, says Ted Craver of Edison International, faces "more change in the next ten years than we've seen in the last hundred." But at least now the rest of us are starting to pay attention.