New approach to electricity measurement could mean fewer blackouts, better automation and more clean energy resources

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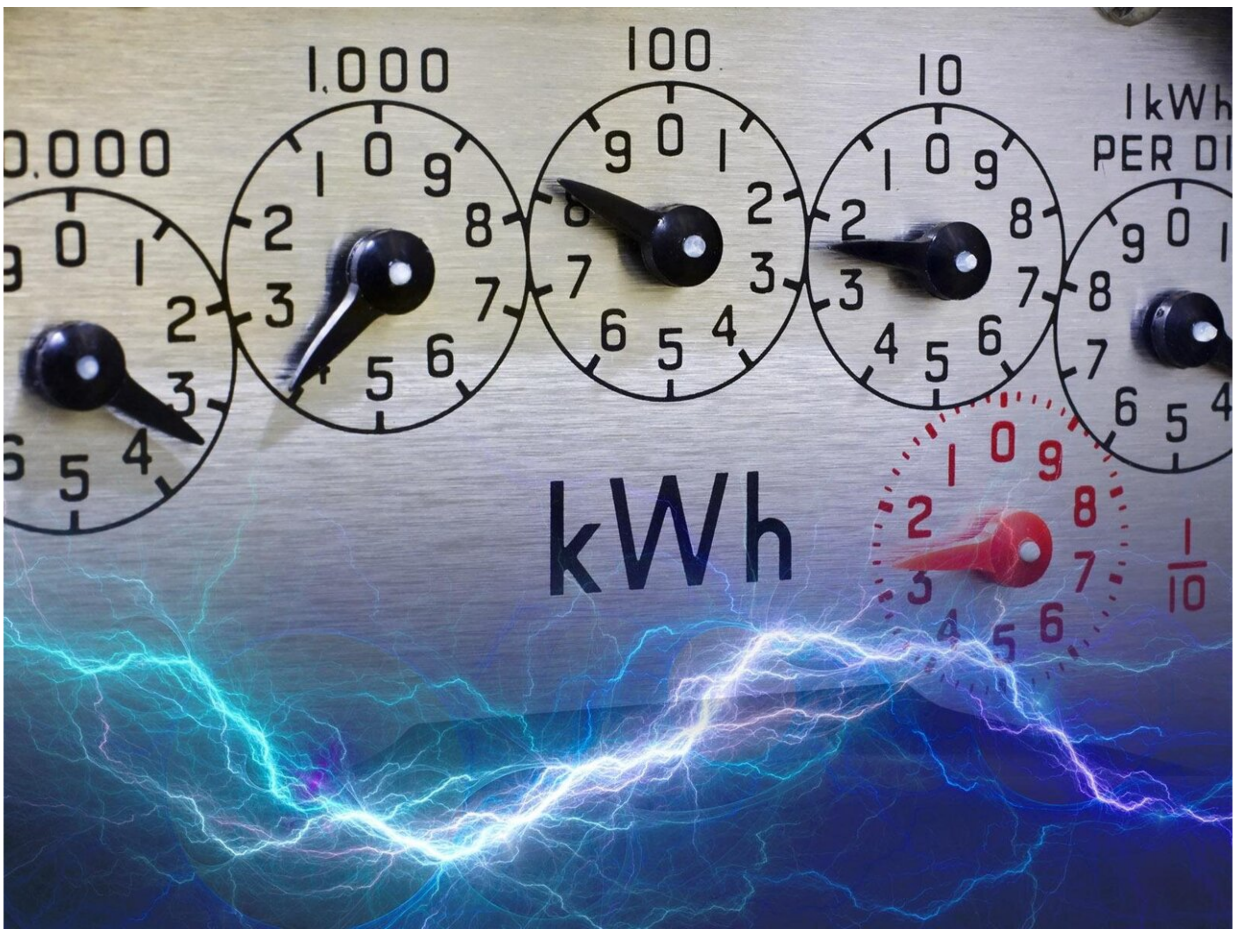

PNNL researcher Harold Kirkham is leading the charge to overhaul outdated electricity measurements. Credit: Shannon Colson | Pacific Northwest National Laboratory

In August 2016, two 500-kilovolt transmission lines in San Bernardino County, California, tripped offline during a fire. As a result, some distance away, more than 1,000 megawatts of solar generation disconnected itself from the grid. Luckily, no one lost power. In contrast, a 2003 component failure in a generator near Lake Erie led to a slightly smaller loss of generation, but the ensuing blackout affected more than 50 million people.

Why did two similar-sized events have such a disparate impact on the power system?

The 2003 blackout and the disconnect in 2016 had different outcomes but, according to Pacific Northwest National Laboratory (PNNL) power systems expert Harold Kirkham, are just two examples of how a tightly coupled system might behave under stress. And the effects of potential errors, combined with a system that's tightly coupled, could have more disruptive consequences as the grid incorporates more diverse—and unpredictable—energy sources like solar and wind power.

Energy in the ecosystem of tightly coupled systems

When the California solar generation tripped offline, automated protection and control systems maintained grid stability. But the solar generation should not have disconnected. It tripped because of a bad measurement. That is, a measurement made by a perfectly functioning instrument doing exactly what it was designed to do.

The chance of a large solar generator disconnecting on a sunny day is not significant, but if it happens when the power transmission system is under stress, there might be a cascade of problems like the one that led to the 2003 blackout in the Northeast.

Kirkham said one effective approach to ward off these potential hazards is improving the methodology and meaningfulness of sophisticated measurements communicated among different parts of the grid. With funding from the U.S. Department of Energy's Office of Electricity and the support of an international group of engineers and scientists, Kirkham is leading an effort to improve power measurements to provide a straighter path to a resilient and renewables-rich power grid.

Insight into electricity measurement

"Measurement exists at the intersection of technology and philosophy," said Kirkham, whose research in measuring electricity goes back to an analog era of "instruments with pointers and scales, and bearings where dust gets in and screws things up." An Institute of Electrical and Electronics Engineers (IEEE) fellow who came to PNNL in 2010 from NASA's Jet Propulsion Laboratory, Kirkham's research has paved the way for advancements in both fields during his five decades of power system engineering.

Kirkham's first concerns about shortcomings in long-prevailing electricity measurement approaches started in 2010 when he was part of a team working to update the IEEE standard for instruments called phasor measurement units (PMUs). PMUs help match the grid's supply and demand using real-time data from multiple points to give a "big picture" depiction of grid conditions. This depiction makes it possible to increase automation and integrate electricity storage, electric vehicles, and intermittent power from wind or solar panels into the power grid.

Early on, Kirkham was friends with the creators of PMUs when the measurements were being developed in the 1980s, and he's seen their benefit firsthand. Still, during some of the meetings to update the standards, he realized there was something fundamentally different between a PMU measurement and other measurements in the power system. PMU measurements could be used to assess measurement quality because the PMU completely characterizes the power system signal, where other measurements merely summarize it.

"I realized that this characterization would allow us to see why the results of many different types of electricity measurements do not match up with what we imagine we're describing," said Kirkham. "That mismatch means errors, power loss, and inefficiencies when both the center and the edges of the grid have many devices and systems that react faster than people can intervene."

The 'how' is as important as the 'what'

Kirkham's decades-long exploration revealed just how far the fields of electricity and measurement had advanced, though sometimes along separate pathways. It's easier to agree on how to measure length or weight because humans can touch and feel the specific things they want to measure, even if they choose a kilogram instead of a pound to quantify it. But measurements fall short when it comes to quantifying abstract concepts like beauty, intelligence, or even some of the things of interest in the power system.

"It used to be almost a joke," said Kirkham, "that we did not know how to define concepts like IQ, but we surely knew how to measure it." But it's not a joke—it's an example of a different kind of measurement.

Over the years, researchers had learned that measuring an abstract concept like intelligence could be untrustworthy if different approaches were used in IQ tests. The solution was always to use the same approach. Standardization was needed. And the same inconsistencies came up in measurements for concepts that seem to have only one foot in the material world. Although the hardness of metals, the octane value of gasoline, and the eyeball pressure captured by glaucoma tests each appear to quantify a distinct physical thing, the "thing" is actually never defined, only the method by which it is measured. To obtain consistent results, all of these measurements rely on a prescribed process.

"You just follow the recipe," said Kirkham. "Air temperature, food calories, wind speed, and many other measurements of this kind."

These measurements are called pragmatic or operational measurements, where the method of measurement is closely defined, because it's difficult to define exactly what it is you're trying to quantify.

Take, for example, the reactive power imagined to be consumed by electric motors in their alternating current's magnetic field. Originally described as the "wattless watt" driven by an "idle current," the concept of reactive power has been so difficult to define that it led to as many as 10 different operational measurements in use today. These different measurements lead to discrepancies and miscommunications that could cost both money and reliability without humans to interpret measurement results for automated grid devices.

Kirkham saw the potential in creating electricity measurement processes that give uniform answers across the power system instead of continuing to write new definitions for things that defy definition. As part of an ongoing international collaboration, he and PNNL electrical engineer Artis Riepnieks developed their own method of implementing PMUs to remove measurement errors caused by real-world distortions.

That development made possible a technique to indicate to devices in the power system when to trust—and when to distrust—measurement results.

"Lines and connections are tripping on and off all the time," said Kirkham. "The power system keeps going because it was built to be robust. Integrating a measurement quality assessment would allow automated devices to appropriately lose trust in the measured result before they react, bringing their performance closer to what human operators expect. There should be fewer examples of what happened in San Bernardino back in 2016."

A power measurement recalibration

The measurement problem is solvable, but Kirkham says convincing the power community could be tricky because the people practicing power engineering today don't necessarily view the issue through the theory of measurement. The solution will require a cadre of multidisciplinary researchers, power engineers, measurement experts, and operators to approach issues with advanced measurement understanding and roll everything out in logical, enforceable standards. Kirkham and his team are putting the finishing touches on standards for the most pressing areas.

"As distributed resources produce energy faster, with less room for error margins in a more diverse energy ecosystem, there's a huge upside to making sure those assets are participating in a stable way," Kirkham said. "We must have measurements that can reveal where we need extra cushions, how big those cushions are, and how much we can trust them. Our system will always be tightly coupled but trusting in the fundamentals of our measurements could prevent a host of problems."

Provided by Pacific Northwest National Laboratory