Renewable energy puts power grids to the test

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To transition away from fossil fuels and towards renewables—which are intermittent by nature—we'll need to rework our entire system of power storage, transmission and distribution. Yet experts haven't yet found the right energy mix or power storage system, or how to balance supply and demand effectively.

Decarbonizing our society will mean replacing much of the oil and gas we currently use with electricity. And demand for electricity will only grow as consumers trade out their heating oil for heat pumps and their combustion engine vehicles for electric ones.

Wind and solar power will meet a growing share of this demand, while nuclear power is set to be phased out, at least in Switzerland. But there's one big drawback to electricity: it's best used right when it's generated, because storing it for more than short periods is difficult and comes with a relatively high economic, environmental and energy costs.

Given the intermittent, variable and decentralized nature of renewable energy, it's clear why we'll need to rethink our existing approach to power grids—or the way in which we generate, carry, distribute and manage electrical power.

A matter of timing

"The more we rely on renewables with unpredictable power generation, the more we'll also need to rely on reserves," says Mario Paolone, the head of EPFL's Distributed Electrical Systems Laboratory (DESL). Especially since today, it's demand that sets the pace.

Demand is seen as immutable, and so it's the supply part of the equation that must be adjusted accordingly. People want to be able to switch on a light, heat up the oven and charge their vehicles at any time of day or night, in the summer or in the winter.

As a result, grid operators keep reserves of electricity on hand that can be tapped into at different time intervals. These include a primary reserve deployable in a few minutes, a secondary reserve deployable within 15 minutes and one hour, and a supplemental reserve for periods beyond that. Each type of reserve comes with the appropriate power storage system.

Fortunately, Switzerland isn't alone. Our power grid is connected to the rest of Europe, allowing us to pool resources, storage systems and costs with other countries. "The dream of becoming self-sufficient in terms of our power supply is neither technically nor financially optimal if we limit our view to Switzerland," says Paolone. "It's Europe as a whole that needs to become energy independent."

Electrifying our processes and transitioning to renewables will impact power grids in two ways. First, it will change how operators balance the load on their grids and store reserves. "For now, synthesis gas made from renewable energy is the most promising method for storing power and responding to seasonal fluctuations," says Paolone.

Gas-fired power plants can step in to meet excess demand. Operators can also set up power-to-gas systems, which use surplus power to produce clean hydrogen, which in turn is processed to make synthesis gas.

"Natural gas companies are really interested in power-to-gas technology because it will let them keep using their existing transmission and distribution infrastructure," says Mario Paolone. "But for that, engineers will need to develop efficient, large-scale carbon capture systems."

He also points out that "as we decarbonize Switzerland, hydropower will play an important role in providing this kind of flexibility to power grids. It's the only completely renewable energy source that we can control. That'll be a crucial advantage going forward."

Hydropower plants provide the flexibility to cover load variations throughout the day or across seasons. Their flexibility depends in part on the type of plant—for instance, whether it's an impoundment plant (i.e., one that collects precipitation and glacier runoff) or a pumped-storage plant.

EPFL recently coordinated the EU's biggest R&D program on hydropower facilities, called XFLEX Hydro. The program studied small-scale modifications that can be made to hydropower plants to increase their capacity, so as to improve the overall reliability of Europe's power grids.

The technology developed under the program can enhance the ancillary services provided by grid operators—the services that continually match supply with demand—which will help keep local and regional grids reliable and make them resilient to fluctuations in the energy supply, both now and in the future.

Batteries to the rescue

When it comes to intraday load balancing, batteries can be a powerful ally. Paolone believes that lithium batteries will be a key feature in tomorrow's decarbonized power grids. "They deliver very high yields and can quickly switch between absorbing and injecting electricity," he says. "These capabilities will be essential for managing primary reserves.

"In addition, lithium batteries will soon be able to complete tens of thousands of cycles. That's a huge benefit for grid operators. The power stations they build are intended to last 10 or 20 years, and the technology is starting to be compatible with that time frame."

What's more, the potential is already out there. "The world's power grids will need a total battery capacity of around 180 GWh/year by 2035," says Paolone. "And at roughly the same time, some 100 GWh to 200 GWh of capacity will become available as electric vehicle (EV) batteries reach end-of-life. It's a perfect match."

There are still some technological hurdles to overcome, however. Engineers at DESL are developing methods for measuring car batteries' residual capacity in order to give them a second life. "We can now determine how many and which cycles second-life batteries can run through within a power grid cycle," says Paolone. "Given that a grid's cycles are much less intense than those in cars, these batteries could be useful for several more years."

Building a stronger grid

The second way that the transition to renewables will impact power grids relates to the grid infrastructure itself. Paolone explains: "We need more power transmission lines. Today, transmission lines at all levels—from very high voltage to distribution—are currently operating at full capacity during certain periods, and this issue will continue to worsen over time."

In Switzerland, assuming nuclear power is phased out and all personal vehicles and residential heating units are electric, we'll need around 40 GWp of photovoltaic power. But the DESL model shows that medium-voltage power lines start getting congested at 13 GWp. So the country will need to make hefty investments to upgrade its power infrastructure.

Local, decentralized power storage systems—or in other words, batteries—would help reduce the need for new power lines. DESL engineers have designed optimization algorithms that, based on the solar power generated within a community and the load on the local grid, can precisely identify where storage systems should be installed and where grid capacity needs to be expanded to minimize the community's electricity costs.

Yet there's another problem standing in the way of finding the optimal energy mix, power storage system and load balancing strategy. "Today, our grids remain stable and reliable due to effective control over power generation, as well as robust grid planning and operational processes," says Paolone. "That's possible because we have relatively few power stations to manage.

"But what will happen when we have millions of decentralized power generators that are outside the control of grid operators? When 1 GW of today's nuclear power is replaced by 5 GWp of distributed solar panels, how will that be managed?

"There'll be an explosion in the number of variables that grid operators will have to juggle. Technically, we could supply all our power needs with photovoltaics, but that would require making major changes to our grid control systems, transmission and distribution systems, and electricity market."

Of course, there's still the demand part of the equation. Another way to reduce our need for power storage is to gain better control over variations in demand.

"If we're able to effectively modulate the load on the grid, then we can do just about anything," says Paolone. Technology being developed in this direction includes control systems for EV charging stations, bidirectional EV charging and real-time variable electricity pricing.

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