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Next for nuclear:

By Matt Wald

Can nuclear power plants prosper in the grid of 2030 or 2035, when new wind and solar farms will make electricity prices even more volatile? Can plants install energy storage that will help them keep running at full power, 24/7, to ride out times of surplus and sell their energy only when prices are high?

Quite possibly, according to a report from the Department of Energy's Idaho National Laboratory. But that energy storage may not be in the form of batteries—at least not what most people think of as batteries, according to researchers. More likely, the energy will be stored as heat, which can be used hours or days later to generate steam and then electricity. Or the energy may be stored as hydrogen, made with electricity plus heat from a reactor, which can be stored in tanks or underground caverns and converted back into electricity when the grid has greater need.

Already with only modest levels of wind and solar generation on the grid, negative pricing is turning into a problem for reactors operating as baseload plants. Free electricity may sound good to consumers. The reality, however,

Energy arbitrage

Research being done at INL's Energy Systems Laboratory is providing information on how nuclear power plants can contribute to effective energy storage and discharge, to aid in arbitrage. (Photo: INL)

is that they do not see the full magnitude of pricing fluctuations and instead pay relatively stable retail rates. For generators that can't vary their output easily, negative pricing can be detrimental.

When prices fall, the response by the manufacturer of most other products would be to make less. Although reactors are developing procedures to do this in a limited way, it is hard to do, and it does not help nuclear economics. "It does not reduce plant operating costs; instead, it increases the cost of nuclear-sourced electric power ($/MWh) as the fixed costs of operations are allocated to a lower production base," according to the authors of the report *Energy Arbitrage: Comparison of Options for Use with LWR Nuclear Power Plants* (INL/EXT-21-62939). "Nor does it represent full asset usage from a capital investment standpoint."

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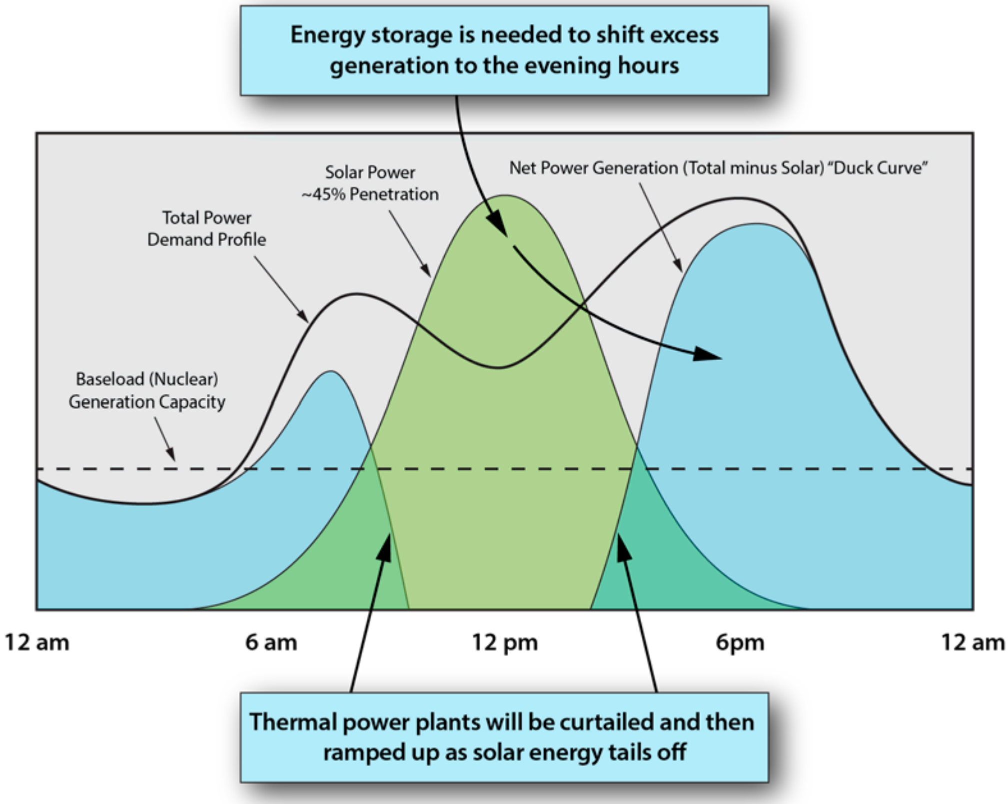


The consequences of excess solar power generation. (Source: INL/EXT-21-62939)

With great power comes great volatility

The study, produced as part of the DOE's Light Water Sustainability Program, is an effort to address a problem already cropping up in scattered locations, but which will grow with the expansion of solar and wind generation. On cool days in spring, a surplus of solar power pushes Western electricity prices below zero. On blustery but mild nights on the western side of the nation's largest power market, PJM Interconnection, wind can do the same. A negative price is the system's way of telling generators to shut down, but nuclear plants can't do that easily. Boiling water reactor operators can change the settings on their recirculation pumps to increase the void fraction, which will cut power production, and pressurized water reactor operators can insert control rods and change the concentration of boron, a neutron absorber, but the procedure is cumbersome.

Even when they do cut production, there are drawbacks: "If they're operating at 70 percent capacity, that's lost energy," said Daniel Wendt, a research engineer at INL and one of the report's authors. To meet state- and federal-level goals for cuts in carbon emissions, the system needs all the zero-carbon energy it can get.

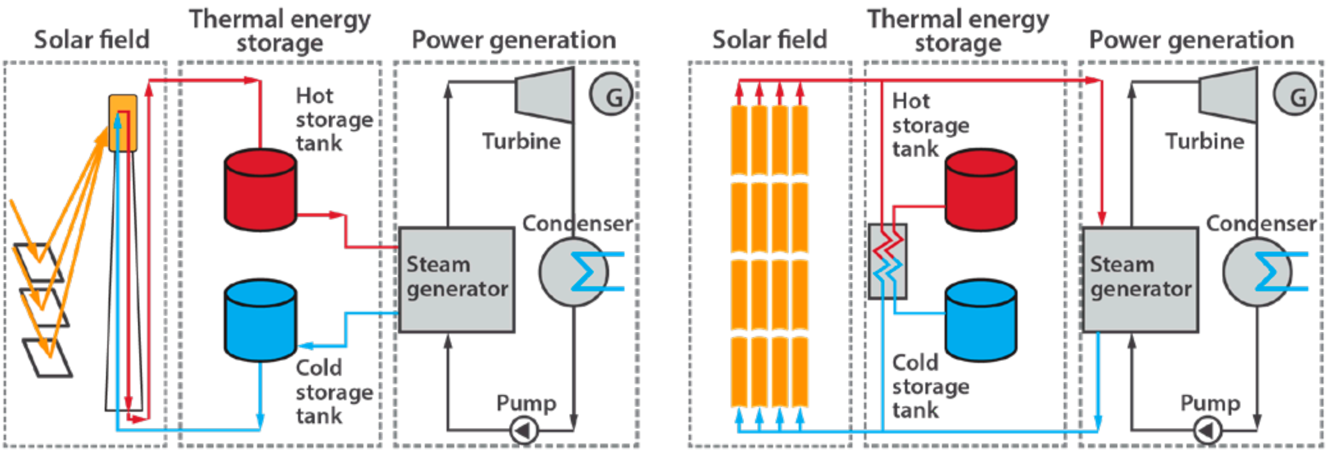
Wind and solar plants, on the other hand, do not need to shut down, because their marginal cost of generation is close to zero, and they can earn a production tax credit that makes them profitable even if they have to pay to put their generation on the grid, which is what happens when prices are negative.

Prices sometimes vary from below zero to a level two or three times the typical price (which can happen when renewables are unavailable). This opens up an opportunity for energy arbitrage, where energy could be stored when electricity prices are low and sold when they are high to increase revenue. Opportunities for energy arbitrage can be region- and market-specific, as the report's authors point out.

Weighing storage options

Energy Arbitrage, published in September 2021, seeks to rank storage technologies by cost. The calculation is complicated, because it is affected by the amount of energy to be stored, the capital and operating expenses, and the duration. Lithium ion and other battery chemistries work well if intervals are short and energy quantities are small. But storing heat works well if the cost of the system to hold the heat, and then make steam and spin a turbine generator, can be amortized over many megawatt-hours. The same is true of the electrolyzers that make hydrogen or the fuel cells or gas turbines that can turn it back into electricity.

Another factor is the round-trip efficiency, which is a measure of how many megawatt-hours you have to put into the system to get one megawatt-hour out. All storage systems are like leaky buckets, but they vary widely. For hydrogen, round-trip efficiency may be as



Solar power tower and parabolic trough concentrated solar power systems with integrated thermal storage systems. (Source: INL/EXT-21-62939)

low as 30 to 50 percent; for lithium-ion batteries, efficiency is in the high 80 percent range.

The study analyzed media for storing heat, hydrogen stored in caverns or tanks and converted back into electricity by a fuel cell or a gas turbine, and lithium-ion batteries. Among the variables analyzed for a given power output capacity were the price per megawatt-hour at which the system would be charged and the number of hours that the system could then discharge at full power level.

For an assumed system with a power level of 500 MWe, delivered for 12 hours, it found that a thermal system storing heat in a fluid called Hitec (a nitrate/nitrite salt already used in the solar thermal industry to carry heat to a steam generation system from mirrored troughs in the sun) could do that for $54 per megawatt-hour, if it charged up when the price of electricity was zero.

A lithium-ion battery system could do the same work for $322 per megawatt-hour. The lowest cost hydrogen system used tanks and a proton exchange membrane electrolyzer and burned the gas in a turbine (probably in a blend with pipeline methane). It had an estimated cost of $71 per megawatt-hour.

While the study looked carefully at storage technologies, it did not explore all of the considerations that a utility or grid entity would have to consider, nor did it explore the alternative uses for hydrogen as a product. Product uses for hydrogen, such as blending into pipeline gas for use in power plants or home heating systems or for industrial use, is the subject of ongoing research studies at INL. It could also be used in cars, trucks, or trains powered by fuel cells or in production of "green steel," where it would replace natural gas. Better yet from a climate standpoint, it could be a substitute for coal.

In all those roles, benefits would include the value of the unused fossil fuels and the value of the carbon not emitted. And utilities that serve well over half the electrical load in the United States have set ambitious carbon reduction goals for themselves, or the states where they do business have done so. In some cases, it is both the utility and the state that have such goals.

Opportunities for further research

Asked if surpluses and negative pricing could enter into a decision to use excess electricity to make hydrogen instead of curtailing a reactor's output, L. Todd Knighton, another author of the report, said, "Possibly, but the decision would be market- and region-dependent."

An additional research question left for another day is market response to the addition of large energy storage systems and the role of storage in correcting upside-down electricity markets. For example, if the system price hit minus $15 per megawatt-hour in a local market, adding a storage system with a capacity of 6,000 megawatt-hours (500 MWe for 12 hours) could push prices above zero, perhaps substantially, because diverting energy to charge the storage system would change the supply/demand balance. If storage installations are large enough, they could reduce or eliminate the volatility that they were built to exploit and profit by.

An additional consideration is what energy source the storage would be tied to. Lithium-ion batteries, whether located adjacent to a reactor or somewhere else on the grid, are simply storing grid electricity. Sometimes energy storage systems are charged up late at night when customer demand is low, by coal plants running extra hours. The storage is discharged

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during peak demand periods. This may save the utility from having to build another power plant, but it also increases carbon dioxide output, because coal is dirtier and storage is inefficient. Batteries adjacent to a solar or wind farm may play an entirely separate role, switching from charging to discharging and back every few seconds or every few minutes to smooth out the production profile. Production curves that are smoother are more valuable to the system, a consideration that will grow as the inventory of variable renewable generators grows. This is still energy storage, but it addresses the variability of solar and wind generation across a few seconds or minutes, not across all the hours of the day.

Nuclear plants have advantages when producing hydrogen over some other forms of generation, the study points out. One is the ability to use heat from the nuclear reactor in high-temperature steam electrolysis (HTSE). HTSE is potentially much more efficient than conventional low-temperature electrolysis (LTE) systems. LTE could be tied to any grid electricity and would require approximately 50 kilowatt-hours to make a kilogram of hydrogen, but if hydrogen is produced via HTSE, the electrical requirement is less than 40 kilowatt-hours per kilogram. A utility could also install HTSE equipment at a thermal solar power plant or a steam-electric plant that runs on fossil fuels, but the fossil plant production would not have the benefit of cutting carbon emissions.

Of course, a company that wanted to build an HTSE system could provide the heat with electricity from resistance heat or a heat pump. But that pathway would take the efficiency hit of using heat made from electricity in order to use electricity to make heat. Using a steam turbine of a typical baseload fossil fuel or nuclear power plant, roughly 33 percent of the thermal energy is converted to electricity. It's far more efficient to borrow a little steam from the secondary side of a PWR to use as the heat source for HTSE.

"If you've got excess capacity, and if you could use that heat directly, instead of taking the hit of converting it to electricity first, that's a big win,'' according to Knighton. But it also requires getting regulatory approval for changes to a nuclear facility to allow heat diversion from the turbine generator, which is a cumbersome process, he said. In theory, a BWR or a PWR could be used, but the PWR represents "the lower-hanging fruit." This is because the steam used to drive a turbine at a PWR is clean. It is using water that is cleaner than tap water. But in a BWR, the steam is made from water that has passed through the core and has trace amounts of radioactive materials. It would require more intermediate heat exchangers and equipment to use this heat in an electrolyzer.

The decision to install energy storage equipment, like making hydrogen from surplus energy, also involves a calculation of the typical swing in regional energy prices at the time that a storage system would come into service. And the charging and discharging would tend to raise the trough (the low point on the variable electricity grid market price curve) and lower the peak.

Results, the researchers say, will vary by region and market. Developers of advanced reactors have taken different approaches to the variability problem.

Natrium, a joint effort of GE-Hitachi and TerraPower supported by the DOE's Advanced Reactor Demonstration Program, will run a reactor at a steady state but interpose a tank of hot salt between the reactor and the power block. The design is meant for diurnal storage, making space for solar during the day but discharging when the sun goes down.

NuScale, which has a design that has been approved by the Nuclear Regulatory Commission, offers a cluster of small modular reactors that are similar to current reactors in that they are light water reactors. But they are much smaller and are designed differently from the plants that are running today and thus can vary their output on a scale of seconds, hours, or days. In its design, operators can send all the steam to bypass the turbine and go directly to the condenser. For longer-term variation, they can shut down a module.

The AP1000 units now approaching completion near Augusta, Ga., can load follow by using "gray rods," control rods that are partially transparent to neutrons that can be inserted to cut power production while allowing even consumption of the fuel.

But the latter two approaches, while simple, result in lost production and, as the INL study points out, reduce the number of megawatt-hours over which fixed plant costs can be spread.

Matt Wald is an independent energy writer and consultant. He is a former policy analyst at the Nuclear Energy Institute and for decades was the energy reporter at the New York Times.

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