Renewable Power: Not Yet Ready for Prime Time

Bernard S. Lee
David E. Gushee
Consultants

Before renewable sources such as wind and solar can contribute significantly to the overall energy mix, massive electricity storage is needed to turn the raw power into dispatchable power.

Massive electricity storage (MES) has been recognized by an increasing number of chemical, mechanical, and electrical engineers as critical to overcoming the major limitation of renewable power — its inherent intermittency *(1–4)*. MES is required to condition the raw wind or solar power, as generated, into dispatchable power for distribution.

Dispatchable power is a block of power that can be transmitted (dispatched) as a reliable, controllable and predictable quantity from the generator to the consumer. For example, a grid operator may contract to deliver a block of power to a utility, say 10 GW for 3 hours (or 30 GWh), and that block of power must arrive at the utility reliably and controllably. If the grid operator is forced to take unlimited intermittent power, it cannot guarantee a block of steady power of 10 GW for 3 h. Without MES, at best it can deliver "an average of 30 GWh over 3 h," with surges of high power levels when the wind blows hard and dips of low or no power. The raw power must be "conditioned" to make it marketable.

Consider the analogy of an oceangoing freighter or railroad cars hauling freight. A shipper will not accept goods packed in paper cartons or plastic bags for large shipments; the materials must be placed in standardized containers of prescribed size and/or weight. Some shippers accept small quantities of loose packages, and charge special handling fees to do so; but in large quantities, goods must first be containerized.

So it is with the need to condition power to make it controllable, stable and predictable — *i.e.*, dispatchable — before it is shipped by the grid operator on transmission lines.

Public support for increased use of renewable power continues to grow, as evidenced by the substantial targets set by many states requiring increasing portions of their power to come from renewable sources. As a result, wind and solar farms have been sprouting up across the nation, and in 2007, the U.S. generated 2.5% of its power from non-hydro renewable sources *(5)*.

Currently, these renewable power sources are directly attached to the electricity grid. The public has been led to believe that greater penetration of renewable power can be achieved simply by attaching more windmills and solar panels directly to the transmission grid. Even though such power is not dispatchable, this has been an acceptable situation at the current low levels of grid penetration.

However, transmission lines cannot deliver large amounts of "spiky" power. Should this spiky power enter the transmission lines, the operator must condition it. This is currently done — when the amount of spiky power is relatively small — with traditional components, such as capacitors, plus adjustments to the operations of existing generating facilities, such as peaking turbines. This requires intense attention to the moment-by-moment condition of the power in the lines; it is expensive, and is awkward compared to handling dispatchable power.

If renewable power is to move beyond 15–20% grid penetration and become a major (>20%) or principal (>50%) source of electricity, the raw power must first be "conditioned" at the point of generation before it enters the grid for long-distance transmission. Dispatchable power — which comes from sources such as hydro, nuclear and fossil fuels, and is reliable, predictable and controllable — is the commodity that grid operators and electric utilities understand how to move and control and have historically built their transmission systems to transmit.

A few simple analogies may help to clarify the concept of power conditioning. Raw natural gas exiting a well is first processed to remove impurities and condensable heavy hydrocarbons before it is injected into pipelines for transmission and distribution. Raw coal is washed and sized to remove impurities and maintain the desired composition and heating value before it is shipped to power plants. In addition, for both of these energy forms, ample storage (whether underground or aboveground) is installed as an integral part of the delivery chain to provide surge capacity and flexibility.

Marketing dispatchable renewable power

The transmission of raw intermittent renewable power on a large scale is not only technically unattractive (if not unfeasible), it is also not economical. For example, a renewable power generator with a nameplate capacity of 100 MW cannot deliver 100 MW of dispatchable power, because the energy source is intermittent. At best, wind and solar power may reach a capacity factor of 35%. Therefore, it is necessary to have nameplate renewable generating capacity of 300 MW to ensure that the grid receives, on average, 100 MW of power for transmission.

Furthermore, although the average may be 100 MW, the grid operator cannot be assured of receiving a steady 100 MW for distribution. To meet its contractual obligation to ship 100 MW of dispatchable power, grid operators must install close to 100 MW of backup generation, typically natural-gas-fired peaking turbines, that can be started or shut down to balance the intermittent renewable power. (In view of the current attention to climate change, it seems paradoxical that a grid transmitting large amounts of raw renewable power would, of necessity, be a large consumer of fossil fuels.) The cost of installing and operating the backup generating capacity should, as a matter of fairness, be allocated to the renewable power.

Germany is the foremost nation in terms of size and extent of its grid, with a national commitment to 20% renewable power by 2020 and grid penetration of nearly 15–20% in some parts of its system *(6, 7)*. Germany has recognized that using gas turbines to back up raw wind power is both technically and economically unfeasible, and that MES must be deployed.

If MES is added to the generation facility, then only dispatchable power is shipped to the grid operator, which no longer needs to provide backup generators to balance the raw intermittent power. The dispatchable renewable power could then be sold at market price and transmitted at the conventional transmission rate, rather than at special rates that may or may not, depending on the local regulatory regime, reflect the costs of providing backup

The Cost of Dispatchable Renewable Power

The following example should shed some light on the relative costs of fossil and non-fossil power *(3, 8, 9)*. To produce 1 kW of dispatchable renewable power, 2.86 kW of nameplate power generation must be installed, due to the 35% capacity factor. At $1,500/kW, the installed cost is $4,300. Adding 0.57 kW of MES (20% of 2.86 kW) at $3,000/kW adds $1,700 to the cost. The total investment, therefore, is $6,000/kW of dispatchable renewable power.

At first glance, $6,000/kW seems high in comparison to fossil power. However, renewable power incurs zero fuel cost. In contrast, the fuel typically accounts for at least 50% of fossil power cost, and fuel cost increases over time. So, the $6,000/kW cost of dispatchable power from renewable generation is equivalent to $3,000/kW of dispatchable power from a fossil-fueled plant.

Continuing R&D and growing penetration will reduce the installed investment cost of renewable power. In addition, any measures to control CO_2 emissions, whether a carbon tax or CO_2 sequestration, will add significantly to the fossil power cost as well as increase the complexity of new fossil power plants and the time needed to construct them.

The encouraging conclusion is that dispatchable renewable power from a generation facility that includes MES is competitive with fossil power today, and should become more so in the future.

As for carbon-free nuclear power, the current cost for new construction is already in the range of $5,000 per kW installed. In addition, the nuclear cycle must be closed — but neither fuel reprocessing nor nuclear waste storage is anywhere near commercial operation. The cost of closing the nuclear cycle will be considerable, and should properly be allocated to the cost of nuclear power. Although nuclear power is and should be an important contributor to the U.S. grid, no one knows how long the nuclear debate will continue. Renewable power is more than competitive with nuclear power, today or in the future.

gas turbines. This will make investment in renewable power generation much more attractive.

From the standpoint of utility rate treatment, dispatchable power from a renewable power plant would, with MES, command a well-understood commodity price, comparable to any other dispatchable power entering a common-carrier grid transmission system. The analogous situation again is natural gas, which is produced and processed by thousands of different providers. The commodity price is set by an established market mechanism, based on uniform gas quality in terms of composition and heating value. The pipelines simply transport the gas for a fee that is consistent with the regulated allowable maximum.

Converting raw renewable power into dispatchable power greatly simplifies the regulatory aspects associated with expanding renewable power, because the cost components can be clearly identified and allocated. The power generator produces dispatchable power whose price is determined by the market. The grid operators transmit the dispatchable power as a common carrier, according to the interstate transmission tariff rates set by the Federal Energy Regulatory Commission. State public utility commissions set the allowable rates that utilities can charge for intrastate transmission and distribution. Adding more dispatchable renewable power to a grid would be no different than adding new fossil-fuel or nuclear power. Thus, no new regulatory regime would need to be proposed, tested and implemented, thereby reducing delays and costs.

Not integrating MES into the generation facility does not obviate the need for MES — it merely pushes the responsibility downstream. The grid operator takes in power from a variety of sources, many of which, such as coal, nuclear or hydro, do not require MES. If the grid operator must invest in MES, the cost would be borne by all power generators, even though it should logically be allocated only to the renewable power.

In addition, integrating MES into the facility that generates the renewable power will simplify power grid upgrading, an issue that is currently of national concern. The upgrade program should support the expansion of conventional dispatchable-power transmission so that it will link points of renewable power generation, which are often in remote areas, with consumption centers. No new technology would be required to expand the grid to handle dispatchable renewable power, and the cost can be reliably predicted. Equally beneficial, with MES, the transmission system would not need to be expanded to carry the nameplate 300 MW when the renewable generation system is running at full capacity — only the requisite dispatchable 100 MW needs to be delivered, and any excess can be stored in the MES system until it is needed at night or after the wind calms down.

Also receiving national attention is the development and deployment of the "smart grid." Smart grid relies on an array of sensors installed on equipment that uses significant amounts of power, such as the household stove, refrigerator, clothes dryer and washer, space heaters, and rechargeable batteries in hybrid cars, and the customer agreeing to let the utility control power usage. If the utility faces a peak period, it can turn off appliances, then turn them on during low-load periods at night. Or it can tap the cars' batteries to draw power to meet peak demands and allow the batteries to charge during low-load periods.

With smart grid, the utility is, in effect, using its customers' appliances and equipment to serve as its "storage" to smooth out the peaks and valleys of demand, which will minimize the need to build more power plants to meet peak demands. But this involves new technology that requires large-scale demonstration. Furthermore, putting this fundamentally new concept — of allowing utilities to control the customer's demand for power — into practice involves complex public-acceptance issues

and will take a long time. The smart-grid initiative deserves federal planning and support, independent of the need to support MES development to produce dispatchable renewable power.

MES technology development

Unfortunately, the MES technology that exists today is not ready for full-scale deployment; it is very early in its technological evolution compared to the forthcoming need. Pumped hydro is a demonstrated technology for electricity storage, and is already widely deployed commercially in the U.S. However, its further contribution to storage is limited by the available sites with an adequate water supply, especially in regions where solar and/or wind installations are likely to be built.

Compressed-air energy storage (CAES) is in operation at one demonstration plant in the U.S., but it, too, is limited by the availability of suitable geologic sites near likely solar/wind installations. Furthermore, energy recovery from CAES is achieved by using the compressed air in a gas turbine, which consumes fossil fuels and cannot provide instantaneous response to the intermittency of wind or solar generators.

Thus, new storage technologies — most likely chemical energy storage — must be developed and demonstrated to meet the storage demand of renewable power. Such MES technologies must:

- charge and discharge multiple times per day
- provide instantaneous response to generator intermittency
- supply hours of storage, as well as be multi-MW in size and multi-MWh in capacity
- have a minimum number and complexity of moving parts for ease of maintenance
- not be constructed of exotic materials (to keep down costs).

Currently three technologies — the sodium-sulfur battery, vanadium redox flow battery, and zinc bromide flow battery — are potential MES candidates. Each has strengths and weaknesses and must be significantly improved. None has been installed at a U.S. wind farm yet. They all must undergo rigorous scaleup to commercial sizes, and their safety and reliability must be established through long-term operation of demonstration facilities.

The U.S. Dept. of Energy (DOE) energy-storage program has historically placed a very low relative priority on research, development, demonstration, and implementation of massive electricity storage. For reliable, economic MES to be available by the time renewable generation's input to the grid will require it, DOE will have to increase the resources devoted to its development through:

- strong, basic research to stimulate innovative new concepts from research teams in academia, industry, independent institutes and national labs
- sustained support for operation from bench scale to pilot scale to demonstrate concept feasibility
- commercial demonstration of promising technologies at operating wind and solar facilities, teaming with manufacturers and utilities
- sustained support for at least 10 years
- a higher relative priority for MES funding
- maximized leverage with funding from industry and state energy programs. **CEP**

Literature Cited

1. **Lee, B. S., and D. E. Gushee,** "Electricity Storage: The Achilles' Heel of Renewable Energy," *Chem. Eng. Progress*, **104** (3), pp. S29–S32 (Mar. 2008).
2. **Lee, B. S., and D. E. Gushee,** "Massive Electricity Storage — An AIChE White Paper," AIChE Government Relations Committee, www.aiche.org/About/WhoWeAre/Structure/Committees/ViewAll/Government.aspx (June 2008).
3. **Lee, B. S.,** "Massive Electricity Storage: A Critical Technology for Renewable Power," Session on "Energy Supply and Consumption in the 21st Century," AIChE Midwest Regional Conference, Chicago, IL (Sept. 22, 2008).
4 **Lee, B. S., and D. E. Gushee,** "Massive Electricity Storage: Fixing Renewable Power's Achilles Heel," session at the AIChE National Meeting, New Orleans, LA (Apr. 7, 2008).
5. **Energy Information Administration,** "Electric Power Annual with data for 2007," U.S. Dept. of Energy, EIA, www.eia.doe.gov (Jan. 2009).
6. **Leonhard, W.,** "Feeding the Grid from Regenerative Sources: The Way to a Sustainable Energy Supply?," *EPE Journal*, **12** (3), pp. 38–42 (Aug. 2002).
7. **Bowler, T.,** "Germany's Wind Farms Challenged," BBC News (May 28, 2006).
8. **Beck, B.,** "Energy Storage and Wind Power Generation — Sizing and Economics," presented at the AIChE National Meeting, New Orleans, LA (Apr. 7, 2008).
9. **Nourai, A.,** "Sodium-Sulfur Batteries for Bulk Energy Storage," presented at the AIChE National Meeting, New Orleans, LA (Apr. 7, 2008).

BERNARD S. LEE (bslee8@q.com) retired from the Institute of Gas Technology as its president. Currently, he lectures and consults around the world, most recently in China and Malaysia, on energy technology and R&D management issues. He holds bachelor's and doctoral degrees in chemical engineering from Polytechnic Institute of Brooklyn and is a Fellow of AIChE.

DAVID E. GUSHEE (gushee1930@embarqmail.com) retired from the Congressional Research Service as a senior specialist in environmental policy. He now consults periodically on issues of energy and environmental policy. A Fellow of AIChE and a past chair of AIChE's Government Relations Committee, he holds a BS in chemical engineering from MIT.