THE ROLE OF ENERGY STORAGE IN RENEWABLE POWER INTEGRATION

EMILY FERTIG AND SHARON WAGNER, CARNEGIE MELLON UNIVERSITY

Mechanical, electrical, and thermal energy storage can mitigate the intermittency and variability of renewable power over a broad range of time scales, facilitating the integration of renewable power into the electricity grid. The appropriate storage technology varies, depending on the specific needs of the renewable power plant. Electrical storage tends to be most efficient, but mechanical and thermal storage are usually more cost-effective overall and can be more practical to implement in systems that already use these forms of energy. In order for storage to successfully support the integration of intermittent and variable resources, several technology-specific issues need to be addressed. The first category of energy storage we consider is mechanical storage (e.g. compressed air energy storage (CAES), hydroelectric power, and flywheels). Two CAES plants are currently operational (one in Alabama and one in Germany) and at least four others are in planning or construction stages. The two operational CAES plants are used for peak shaving, arbitrage, and to supplement the ramp rates of base-load generators. CAES stores enough energy to smooth daily variability in wind and solar power output and can ramp quickly enough to smooth hourly fluctuations. One planned CAES plant, the 2700 MW Iowa Stored Energy Park in Dallas Center, Iowa, will be used specifically to smooth wind power output. Current CAES systems use natural gas and have a heat rate about two-thirds that of an efficient natural gas combined cycle plant. It is possible that adiabatic CAES systems, which avoid the use of natural gas by storing the heat of compression and using it to reheat the air that exits the cavern, will be feasible in the near future. CAES is more cost-effective than present battery technology at the GWh scale, and can be sited in suitable geology across much of the United States. Directions for future work include the demonstration of adiabatic CAES and a more thorough valuation of the services CAES provides in different electricity markets under varying levels of renewables penetration.

Like CAES, pumped hydroelectric storage provides quick-ramping large-scale electricity storage that could provide a range of ancillary services including regulation, reserve, and capacity. Pumped hydroelectric storage requires two bodies of water at different heights, and is thus feasible only in a limited number of locations. The cost-effective and environmentally acceptable locations for pumped hydro are largely already developed, leaving little opportunity for expansion of this technology. Run of the river-hydro storage may also be able to support intermittent power generation. Research is needed in all aspects of this storage option to better evaluate its suitability.

Flywheels generally produce 100 to 2000 kW for 5 to 50 seconds, and are thus best suited for high-power, low-energy applications such as grid angular stability and voltage support. Areas for future work include materials development, cost reductions, and improved manufacture techniques[1].

Electrical energy storage technologies with applications for renewable integration include batteries and capacitors. Batteries can store and release power across a broad range of time scales, smoothing rapid fluctuations in the output of renewable generators or mitigating daily variability. Despite their operational flexibility and potential to provide a wide range of ancillary services, batteries have yet to attain high penetration at grid scale. High cost remains a deterrent, as does a lack of demonstration. The U.S. Department of Energy has begun to provide partial funding for storage projects; including a planned 20-MW lithium ion battery system in New York that will provide frequency regulation services and help

---

[1] Gyuk, I. and Eckroad, S., 2003. EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications, Electric Power Research Institute and U.S. Department of Energy.

integrate increased wind and solar capacity[2]. If the cost of batteries drops as anticipated due to technical innovation and increased production volume, use of batteries for grid applications such as regulation, renewable integration, and transmission upgrade deferral could expand substantially.

In addition to standalone batteries, widespread plug-in hybrid electric vehicles (PHEVs) could be used as distributed grid storage for applications including daily load leveling, reserve, or frequency regulation. Large-scale use of PHEVs would also help reduce the cost of some types of batteries by both stimulating competitive innovation and increasing required production volume. If PHEVs are to be an asset to future electricity grids, consumer choices on the timing of vehicle charging will need to conform to the needs of the overall system. Research is needed to quantify the public and private benefit of using PHEVs for electricity price arbitrage, and to identify the policy incentives necessary to align consumer behavior with maximum social welfare.

Thermal energy storage (TES) refers to the storage of hot or cold energy for later use. On the demand-side, “hot” TES is usually coupled with rooftop solar thermal collectors, which capture heat energy during the day to be stored in a hot water tank. This type of system incurs a high up-front capital cost but may prove cost-effective over time depending on electricity prices and economic incentives. A “cold” TES system runs a chiller at night to generate ice, which is used during the day to produce chilled water for air conditioners. This system is designed to shift electricity demand for air conditioning (the bulk of peak demand[3]) from day to night. As these demand-side initiatives become more wide-spread, they could contribute greatly to electricity and greenhouse gas reductions. However, future research is needed to quantify this potential, to determine optimum system sizing for maximum economic returns, and to identify policy initiatives to encourage more widespread deployment.

On the supply-side, TES is commonly associated with concentrated solar thermal power (CSP). In this system, the heat energy from the sun is transferred to a solid or liquid phase change medium (molten nitrate salt is currently favored) and stored for later use, when the heat is transferred to a steam power cycle to drive a turbine. This technology was demonstrated successfully at Solar Two (10 MW) in Barstow, CA from 1996 to 1999[4], and has been in commercial operation at Andasol 1 in Spain since 2008. TES is especially applicable to CSP because it smoothes out variation in solar power during the day and allows electricity generation into nighttime peak demand hours. However, TES raises the already high capital cost of a CSP plant. Key areas of research for this technology include: 1) reducing system capital costs, 2) quantifying the long-term effect of TES on the operation and maintenance of a CSP plant, 3) evaluating the profitability of different TES configurations, 4) evaluating the effect of different policy initiatives on the decision to use TES at a CSP plant, and 5) comparing the economic and environmental implications of TES for power tower and parabolic trough technologies. These last two areas of research are especially important because TES is more efficient and cost-effective when coupled with power tower than with parabolic trough CSP[5]. However, parabolic trough CSP is currently the industry leader, and as TES becomes more important to CSP, it may be worthwhile to examine policy initiatives that shift industry preference to power tower.

---

[2] LaMonica, M. Giant battery smooths out variable wind power. CNET News, 8/4/2010. http://news.cnet.com/8301-11128_3-20012597-54.html

[3] Du Bois, Denis. "Ice Energy's "Ice Bear" Keeps Off-Peak Kilowatts in Cold Storage to Reduce HVAC's Peak Power Costs (Energy Priorities)." *Energy Priorities*. 16 Jan. 2007. Web. 21 Aug. 2010. <http://energypriorities.com/entries/2007/01/ice_energy_peak_power.php>.

[4] USA. Department of Energy. Energy Efficiency and Renewable Energy. *Concentrating Solar Power: Energy from Mirrors*. DOE, 2001. Print. DOE/GO-102001-1147.

[5] Price, H., ed. "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts". Rep.No. SL 5641. Sargent & Lundy LLC Consulting Group. Chicago, IL: NREL, 2003.

In addition to all the technology-specific issues previously discussed, a pertinent issue that applies to all energy storage technologies is how to value the storage service. An accurate valuation would consider the following key factors: 1) air quality and economic benefits of offset generation capacity, 2) firming of renewable power to help fulfill renewable portfolio standards, 3) avoided construction of new transmission capacity and transmission congestion relief from renewable power generators, 4) relief of ramping requirements for base-load generators, 5) overall reduction in the cost of ancillary services, and 6) deferral of substation upgrades. An accurate assessment of these benefits would support energy firms making investment decisions as well as policymakers considering subsidies to storage technologies.

The RenewElec project will work to identify the storage strategies most appropriate to support the integration of renewable resources. Such work will include quantifying the storage potential for different technologies as wells as their associated costs and benefits. In addition, we will work to identify how grid and power plant operators will need to adapt to support storage. Finally, we will look at market and regulatory strategies needed to support the implementation of storage technologies.