Flywheel Energy Storage – a Smart Grid Approach to Supporting Wind Integration

Chet Lyons (Beacon Power Corp.) — Tyngsboro, Massachusetts, USA — lyons@beaconpower.com

Wind developers face tough challenges in integrating and operating wind resources on today's grid. A recently commercialized inertial energy storage technology can help address several issues of common interest to wind developers, utilities and grid operators. These include the need for more regulation to help balance generation and load as wind penetration rises; the projected shortfall in some grid areas of regional ramping capacity that is needed to cope with wind's variability; and the difficulty of developing wind generation in smaller balancing areas that lack sufficient regulation and ramping capacity.

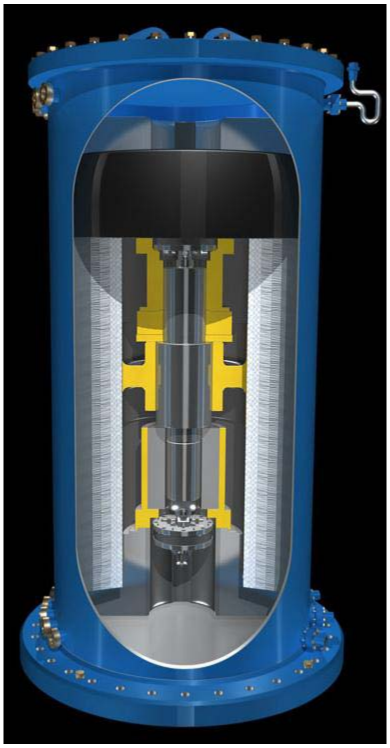
After more than 10 years of development and successful scale-power tests in California and New York, in 2008 Beacon Power began operating the world's first commercial 1 MW flywheel frequency regulation system under ISO New England's Advanced Technologies Pilot Program. Beacon's resource has since expanded to two megawatts, and by the end of 2009 is expected to be three megawatts. (See Figure 1)

Figure 1: 1 MW Flywheel Regulation System Operating in New England

Flywheels are installed below grade while the power electronics, monitoring and control systems are housed in a steel cargo container

A flywheel energy storage system is elegant in its simplicity. The ISO monitors the frequency of the grid, and based on North American Electric Reliability Corporation (NERC) frequency control guidelines the ISO decides when more or less generation is needed to balance generation with load. When generation exceeds load, the ISO's regulation dispatch control signal directs the flywheels to absorb energy from the grid and store it kinetically by spinning the flywheels faster. When there is not enough generation on the grid to meet the load and frequency falls too low, the ISO signals the flywheels to release their energy to the grid. Together with a vacuum-enclosed high-speed rotating carbon and fiberglass rotor levitated on magnetic bearings – an advanced motor/generator and inverter system make this highly useful energy transition possible. (See Figure 2 on the following page)

Figure 2: Smart Energy 25 Flywheel



Each flywheel can release and store energy at up to a 100 kW power level; ten flywheels make up a 1 MW Smart Energy Matrix.

Key features of flywheel-based regulation are its extremely fast response (many times faster than conventional fossil fuel generators used for regulation); its high round trip efficiency (about 85 percent); its ability to cycle extensively without losing any storage capacity (> 150,000 full charge/discharge cycles), its low maintenance cost; and the fact that it produces zero direct CO_2 or other emissions.

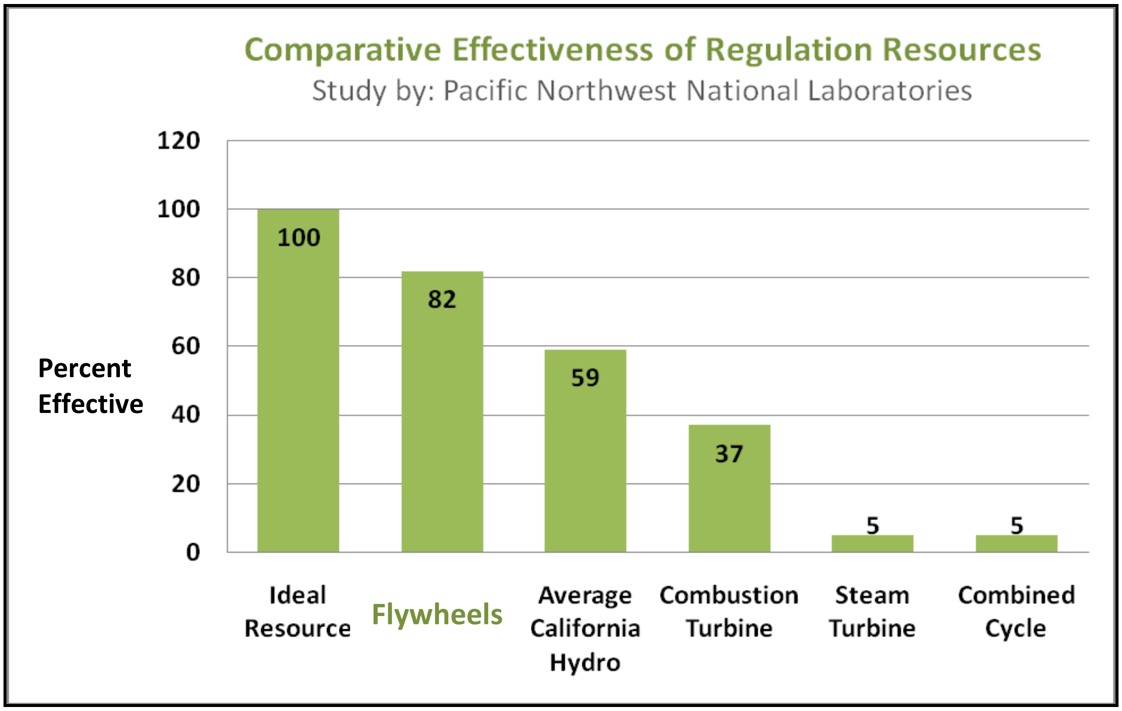
Storage-based regulation technology can help alleviate concerns about new regulation and ramping capacity that will be needed as more wind and solar generation assets are deployed. The California ISO, for example, estimates that by the time 20% of its electricity is supplied by renewable resources, regulation requirements will need to have been increased from 170 MW to 250 MW for so-called "up regulation" and 100 MW to 500 MW for "down regulation," depending on the season and hour of the day.[1] Without some new approach, regulation costs will rise as a result. While regulation costs are still generally socialized across balancing systems, pressure from stakeholders to allocate these costs directly to wind developers will increase if they go up significantly. A technology that can reduce these costs might "take the wind out" of the call for tariff changes that would hand the bill to wind developers.

Just how much cost could energy storage-based regulation cut? Pacific Northwest National Laboratory (PNNL) tackled this question in its study: "Assessing the Value of Regulation Resources Based on Their Time Response

[1] Source: California ISO report: "Integration of Renewable Resources, Transmission and Operating Issues and Recommendations for Integrating Renewable Resources on the California ISO-controlled Grid."

Characteristics."[2] The study defined an "ideal" regulation resource as one with infinite energy that can respond instantly with perfect accuracy to any system imbalance. The effectiveness of each type of regulation technology was then compared to this ideal resource. The study found that 1 MW of fast-response regulation should deliver about twice the system regulation value of the average conventional regulation resource in California. Because California's average resources include a large percentage of relatively fast-response hydro, even this doesn't tell the whole story. The study also found that fast-response regulation may be as much as 17 times more effective than some types of conventional ramp-limited regulation resources. Further, if California's regulation fleet included about one-third of such fast-response resources, California's system-wide regulation capacity requirement could be reduced by about 40%. (See Figure 3)

Figure 3: Comparative Effectiveness of Regulation Resources



As impressive as a 40% capacity (and cost) reduction would be, if a carbon cap-and-trade program is adopted as federal policy, the benefits may be even greater. A large amount of regulation in the U.S. is done with carbon-intensive coal-fired units, and a carbon tax will increase the cost of regulation from those resources. Energy storage systems do not burn fuel, so they emit zero direct CO_2. Even including the carbon footprint of make-up energy that storage-based regulation providers must buy to account for inefficiency, storage-based regulation produces far less CO_2 than fossil fuel regulating generators. A study by KEMA showed that coal and natural gas-fired regulation increases fuel consumption for those plants by 0.5 to 1.5 percent.[3] Assuming a midpoint value of 1 percent, flywheel-based regulation will cut (direct plus indirect) CO_2 emissions by about 50 percent compared to base load gas-fired regulation generators. The reduction would be up to 85% compared to base load coal-fired regulation resources.

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[2] See: Makarov, Y.V., Ma, J., Lu, S., Nguyen, T.B. "Assessing the value of Regulation Resources Based on Their Time Response Characteristics." Pacific Northwest National Laboratory, PNNL – 17632, June 2008.

[3] "Emissions Comparison for a 20 MW Flywheel-based Frequency Regulation Power Plant," KEMA, Inc., May 2007; principal contributors: Richard Fioravanti, Johan Enslin; funded by US DOE through Sandia National Laboratories.

Another reason to favor energy storage-based regulation is its fast response. Energy storage-based regulation can go to full "up" or "down" in a few seconds, even faster if needed. As wind penetration increases there is a greater need for more ramping capacity. Reserve generation units that lumber to full output in 10 minutes will not be enough to meet the regulation and ramping requirements of the future. Either we will need considerably more of these ramp-limited reserves, or we must deploy resources with much faster ramping capability. Recent ramp-rate limitations imposed on wind resources by Hawaii Electric Company (HECO) are an early indication of the increasing seriousness of this issue.

Under HECO's new rules, the ramp rate of some new wind assets may no longer exceed 2 MW per minute (up or down). Each wind developer must now solve its own ramp rate requirement with whatever bolt-on solutions are available. While this requirement may translate to a new opportunity for energy storage providers, asking each wind developer to solve ramp-rate limits in this way will be costly – and counter to the Smart Grid principle of "highly integrated resources." Indeed, NERC asserts: "The benefits of energy storage are most broadly realized and valuable when operated as a system resource for the benefit of the entire system, and not in a dedicated mode for any individual resource such as variable generation plants."[4] A more efficient and less costly approach would be to augment and/or replace some conventional slow-ramping regulation resources with fast-response energy storage-based regulation – and to share those fast-response Smart Grid resources across the entire grid network.

Another benefit of energy storage-based regulation is that it is a single-purpose solution. One can deploy just the amount of regulation needed. In contrast, conventional regulating generators must also produce base load energy in order to provide regulation – and a customer (or customers) must be found to buy the base load energy. This can be problematic in smaller balancing areas with limited load growth. Sparsely populated areas may not need more base load generation, and transmission limitations can further complicate the problem by limiting the ability to export new base load energy to distant buyers.

A final challenge for conventional regulation technologies is the long lead time required for siting and constructing fossil-based regulating generators. Because it requires no fuel supply and has zero direct emissions of any type, an energy storage-based regulation resource can be sited, permitted and built in about 18 months, versus two to five years for a fossil-based regulating generator. Given these circumstances, storage-based regulation can be a far more practical and less costly solution.

Energy storage-based regulation is new in the market and its advantages are not yet widely known. But with the commercial availability of this new technology, the higher value of fast-response energy storage regulation should be carefully considered by stakeholders and policy makers. This includes greater regulation effectiveness, zero CO_2 emissions, the ability to support regional ramping, and the ability to offer regulation à la carte and get it into operation in a timeframe that works for developers.

Policy makers and ISOs have recognized the economic and environmental potential of energy storage technology and good progress has been made in changing market rules to allow this technology to compete. An important step is that FERC has now approved the country's first and second energy storage-based regulation tariffs for the Midwest ISO (MISO) and New York ISO (NYISO). California is advancing in a stakeholder process that is expected to result in a storage-based tariff for regulation in 2010. ISO New England has an energy storage pilot program underway whose purpose is to develop permanent market rules for storage-based regulation. PJM Interconnection's market is also open to energy storage-based regulation. But there is more to do on the regulatory front. Stakeholders who want to encourage the deployment of this wind-friendly technology can help by:

- Asking FERC, PUCs and ISOs to allow energy storage-based regulation to compete in both open bid and vertical markets on an equal footing with legacy regulation resources;

- Asking FERC and ISOs to place a performance-based value on fast-response regulation that is pegged to its actual regulation and balancing impact on the system, which includes the ability of fast-response storage to provide short term (up to 30-minutes) wind ramping support;

[4] Source: "Accommodating High Levels of Variable Generation," page 46; NERC, November 2008.

- Supporting federal tax incentives for energy storage-based regulation equivalent to those received by solar and wind, including 5-year MACRS depreciation and a 30 percent Investment Tax Credit (optionally fundable from the U.S. Treasury).

Figure 4: 20 MW Flywheel Energy Storage Regulation Plant

20 MW flywheel regulation plant planned for Stephentown, New York.

About the author:
Chet Lyons is the Director of Marketing and Sales for Beacon Power Corporation. He has over 25 years of experience in business development, marketing and sales of energy technologies. He has held related positions at Johnson Controls, Energy Resource Associates, American Superconductor and Evergreen Solar. He has also consulted to energy utilities in the U.S. and overseas. Technologies he has helped to commercialize include superconducting generators and cable, photovoltaic and thermal solar systems, and flywheel energy storage. He holds an undergraduate degree in Environmental Studies from the University of California, Berkeley, and an MBA in Finance from Boston University's Graduate School of Management. Contact: Lyons@beaconpower.com, T: 978-661-2831