# MANAGING THE STATE OF CHARGE OF ENERGY STORAGE SYSTEMS USED FOR FREQUENCY REGULATION

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## ABSTRACT

This paper summarizes approaches used by Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) in managing the state of charge of energy storage systems used for frequency regulation (an ancillary service supporting power balance on the grid). Two different approaches have evolved and been tested and will be summarized. This paper uses commercial field data to show the benefits of fast performance, to highlight lessons learned, and to suggest how to best use the assets in the future.

**Keywords**: frequency regulation, flywheel, policy, state of charge management

## INTRODUCTION

Frequency regulation on a power grid is an ancillary service used to balance power generated and load to maintain a target frequency, usually 60 or 50 Hz. It is also used to manage unscheduled tie flows for a given balancing area to net at zero within a 15-minute time period. Deviation from this balance is called Area Control Error (ACE). Historically, frequency regulation was provided by generators whose outputs were regulated to follow the system operator regulation signal using an automatic generator control (AGC). Typically, the generator was required to fully respond to the signal in 5 minutes. This response time is significantly slower than the few seconds a load can change with the throw of a switch. Existing market rules recognized generation as the only asset that could provide this ancillary service. In 2007, the Federal Energy Regulatory Commission (FERC) issued Order No. 890 mandating market rule changes that would open competition to other technologies. Energy storage using a flywheel-based system was proposed to provide frequency regulation as a low-cost alternative.

Grid operators considering storage alternatives for frequency regulation expressed concern that if the imbalance lasted too long, it might be possible to either fill or empty all the energy from the storage device, negatively affecting performance. There was also the question of whether storage is a generator or a load. The classification made a big difference insofar as who could own and operate such a system in a deregulated environment. It was recognized that energy storage at times behaved like a generator, and at others like a load, but neither conventional generator control nor demand response were adequate to manage the storage device. It became apparent that storage resources required their own control methodology. See Figure 1. The approach taken by the Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) was that storage should be treated in one of two ways:

(1) Manage the state of charge so as to treat the device as a generator when nearly fully charged, and as a load when nearly empty.

(2) Devise a way to control the storage system with an energy-neutral control signal (zero bias), so that the charge of the system never gets empty or full.

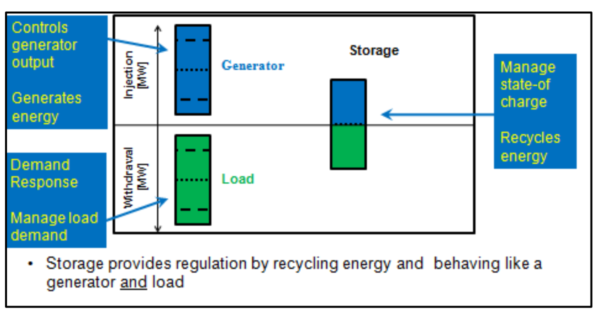


**Fig. 1. Separate asset class for energy storage.**

In responding to FERC Order No. 890, the ISOs developed creative state-of-charge methodologies using one of those two approaches to ensure the storage.

### Speed Matters

It was recognized that the effectiveness of ACE correction is actually a function of both the amount of megawatts (MW) of imbalance and the time it takes to correct the imbalance. See Figure 2. The amount of balancing energy delivered by a slow-ramping generator, shown on the right, is limited by the ramp rate, but can continue indefinitely. The faster the ramp rate, the more balancing energy can be delivered. Independent System Operators-New England (ISO-NE) recognized this and has used the approach of dispatching fast assets first, with the result that they require a lower percentage of average load than other ISOs. Energy storage, on the other hand, has the ability to respond and even reverse direction much quicker and therefore deliver more balancing energy, but can be limited in energy. In addition, slow-ramping resources cannot switch directions quickly. They sometimes provide regulation in a direction that is counterproductive to the needs of the grid and, as a result, actually add to the ACE, requiring another resource to be dispatched to counteract it.

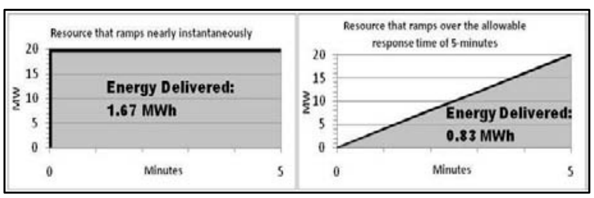


**Fig. 2. Fast ramp capability is more effective.**

The Frequency Regulation Pilot Program in ISO-NE shows a comparison of the two characteristics plus the effect of dispatching the faster resource first. See Figure 3. The energy delivered by the storage device is the area under the signal curve. (The signal and storage response are on top of each other.) The ramped curve represents a response of a generator with a 5-minute response. Notice the significant difference in delivered energy (area under the curve) between the storage and generator assets.

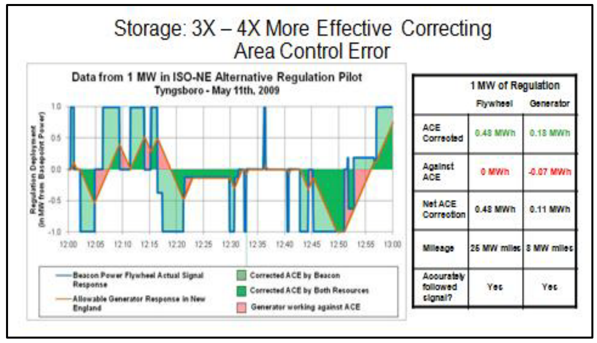


**Fig. 3. Effectiveness comparison of storage and conventional generation-based regulation.**

## ISO/RTO RESPONSE SUMMARY

The paper will describe in detail how the RTOs approached storage-based systems. Data from the 20-MW plant in Stephentown, NY, will be used to illustrate New York Independent System Operator (NYISO) performance. The next plant to be built will be in Hazle Township, PA, within PJM control. Status of that plant will be reported.

### NYISO/MISO

Both NYISO and Midwest Independent System Operator (MISO) implemented a four-step process to accept storage [1]:

(1) Create a new storage asset category called Limited Energy Storage Resources (LESR) and allowing resources to supply regulation only with no requirement to supply energy;

(2) Develop a method to manage the state of charge in the storage device utilizing a 5-minute energy market;

(3) Modify their dispatch to take advantage of fast response by treating storage as a "first responder," which reduced reliance on slower-responding units; and

(4) Devise a new net energy settlement for LESRs (*Hourly settlement = (energy in – energy out) x LBMP).*

FERC approved both tariffs in 2009.

### ISO-NE

ISO-NE recognized the AGC signal was not neutral and caused the storage device to either fill or drain empty. They launched a pilot program to develop methodology to address this issue. Beacon Power created an algorithm that modifies the base point and treats the asset like a generator when near full, and like a load when near empty. Process forces state of charge to maintain mid-point energy.

### PJM

PJM took a two-signal approach: a conventional AGC signal for generators and an energy-neutral fast ramping signal for storage. This approach was used with an AES energy storage demonstration in PJM. PJM is awaiting FERC approval of their tariff.

### CAISO

California Independent System Operator (CAISO) tested a split-signal approach (see Figure 4) using Beacon flywheels in 2006 where the regulation signal was divided by using a rolling 5 to 10-min average to control generators and reduce the number of reversals and ramp rate requirements. The rest of the imbalance was sent to the storage device. CAISO has recently submitted their tariff to FERC and is awaiting approval.

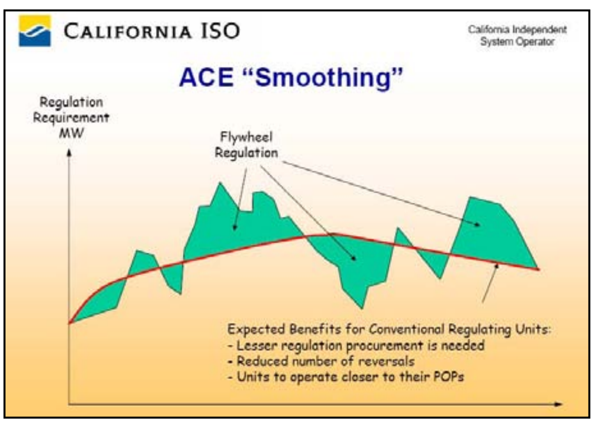


**Fig. 4. CAISO approach to signal split.**

## REFERENCES

[1] R. Mukerji, R. Pike, and J. Hickey, *Integration of advanced storage technologies in the New York wholesale electricity market*, CIGRE document C5_210_2010.

## BIOGRAPHICAL NOTE

Mr. Lazarewicz has been with Beacon Power Corp. for 12 years, where he serves as Vice President and Chief Technical Officer. Before joining Beacon Power, Mr. Lazarewicz worked for 25 years for General Electric in various engineering and managerial capacities in Power Systems and Aircraft Engines. He is a Mechanical Engineer and holds B.S., M.S., and MBA degrees from the Massachusetts Institute of Technology. He is also a Registered Professional Engineer in Massachusetts. He serves as Vice-Chairman of the Electricity Storage Association, Chairman of the Energy Storage Working Group of the Distributed Generation and Energy Storage Sub-Committee, and a member the Institute of Electrical and Electronics Engineers (IEEE) Power Engineering Society, American Society of Mechanical Engineers (ASME), International Council on Large Electric Systems (CIGRE), and the National Electrical Manufacturers Association's (NEMA's) Energy Storage Council.