



# Beacon Power Corporation

## Flywheel Energy Storage Technology

Prepared for:

# ERCOT Power Storage Working Group

August 24, 2010



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# Beacon Power Flywheel Energy Storage



- **Fast Response Regulation**
  - Recycles electricity to balance fluctuations in supply and demand
  - Stores energy when supply exceeds demand; injects power when demand exceeds supply
- **“Grid Ready”**
  - Successful demonstrations in NY and CA
  - 3 MW operating in ISO New England pilot program
  - 60 MW of commercial projects under development
    - Constructing 20 MW plant in NY; Received \$43 million DOE loan guarantee, \$2 million NY grant
    - Developing 20 MW plant in PJM; Awarded \$24 million DOE grant
    - Developing second 20 MW plant in NY



# Benefits of Storage-based Regulation

- Speed greatly improves regulation performance, lowers cost to ratepayers
  - Up to 100x faster response than current providers
- Available a la carte
  - Reduces the need to run additional generation units at night in order to control wind
- Very low operating cost, high efficiency
  - New competition displaces higher cost traditional regulation resources
- Zero direct CO<sub>2</sub>, NO<sub>X</sub> and other emissions (no fossil fuel)
- Frees generation capacity (1- 3%)



# ISO New England 3 MW Flywheel pilot project



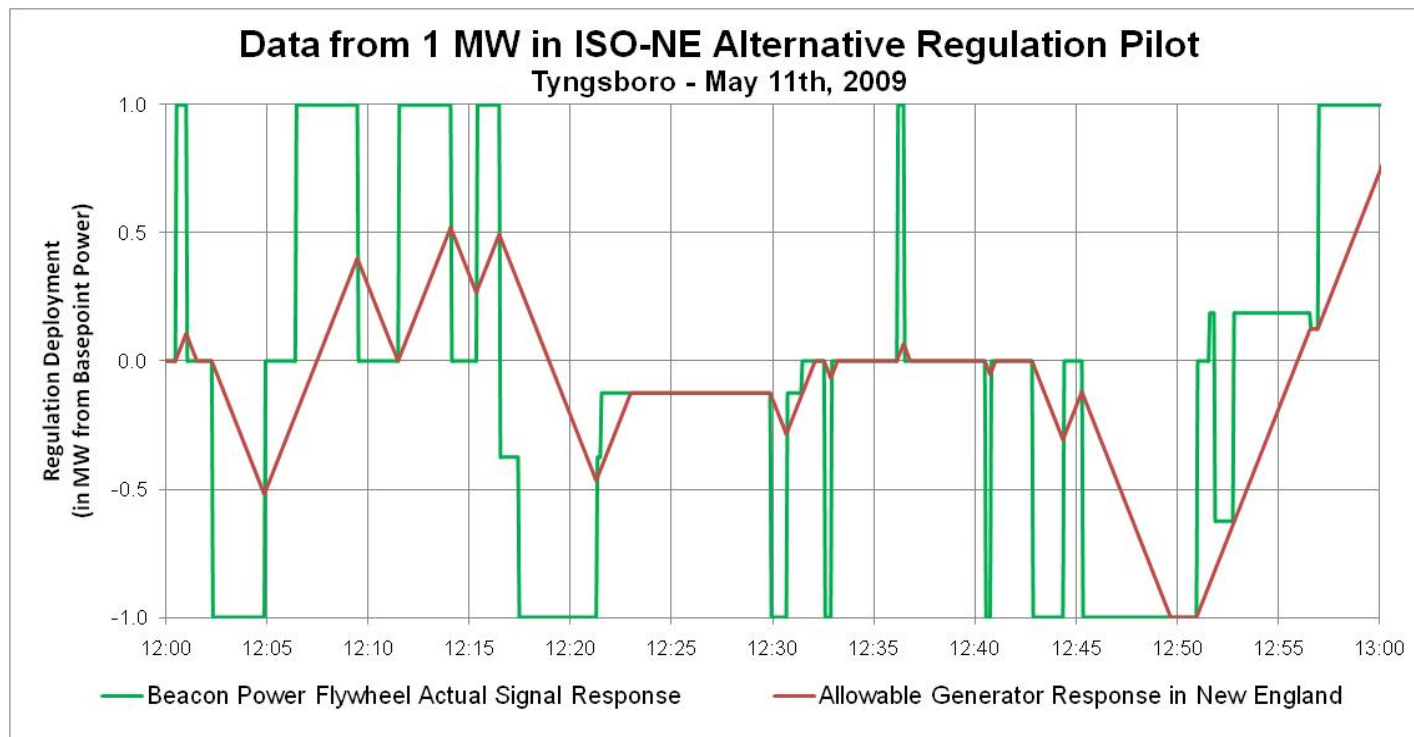
- Beacon Power has 3 MW of flywheel energy storage successfully operating in the ISO-NE Alternative Technologies Regulation pilot program
- “Fast first” Regulation dispatch
- “Mileage payment” encourages higher ramp rates
- ISO-NE procures least amount of Regulation per load than any other ISO; 0.66% of average load in 2009
- FERC held technical conference on this method of regulation compensation on May 26, 2010



# ISO-NE Pilot Program Empirical Data



- 1 MW of flywheels responding within four seconds to a fast, frequently changing regulation signal (green line)
- Versus the response of a Generator providing 1 MW of Regulation that takes 5 minutes (the allowable response time) to ramp to its full output

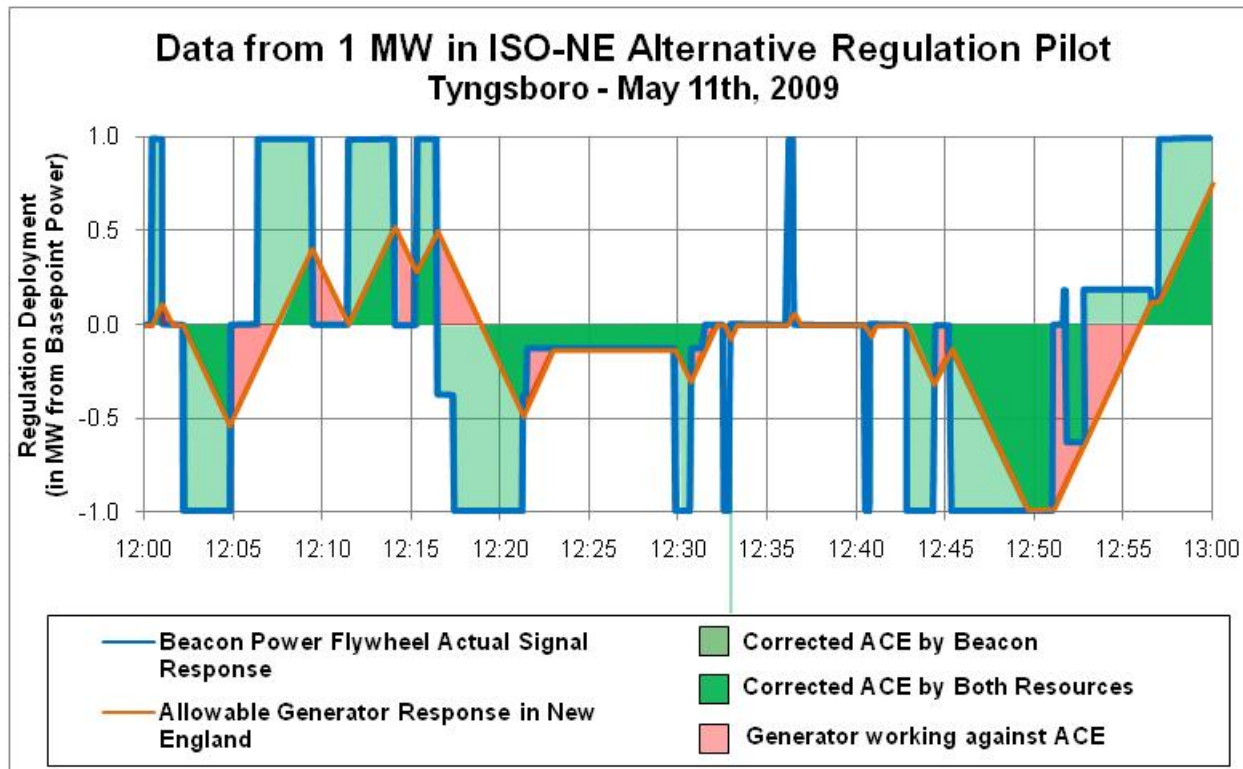


**Flywheels provide near instantaneous response to a control signal  
2 – 3 times more “mileage” than average generator**

# Fast response resources provide more ACE Correction per MW offered



- Per MW offered, Beacon Power with its under 4 second response time is correcting more of the Area Control Error (ACE) as compared to a generator with a 5 minute ramp
- In addition, slow ramping resources can add imbalance to the system because of their inability to quickly change direction (from 'Up' to 'Down')



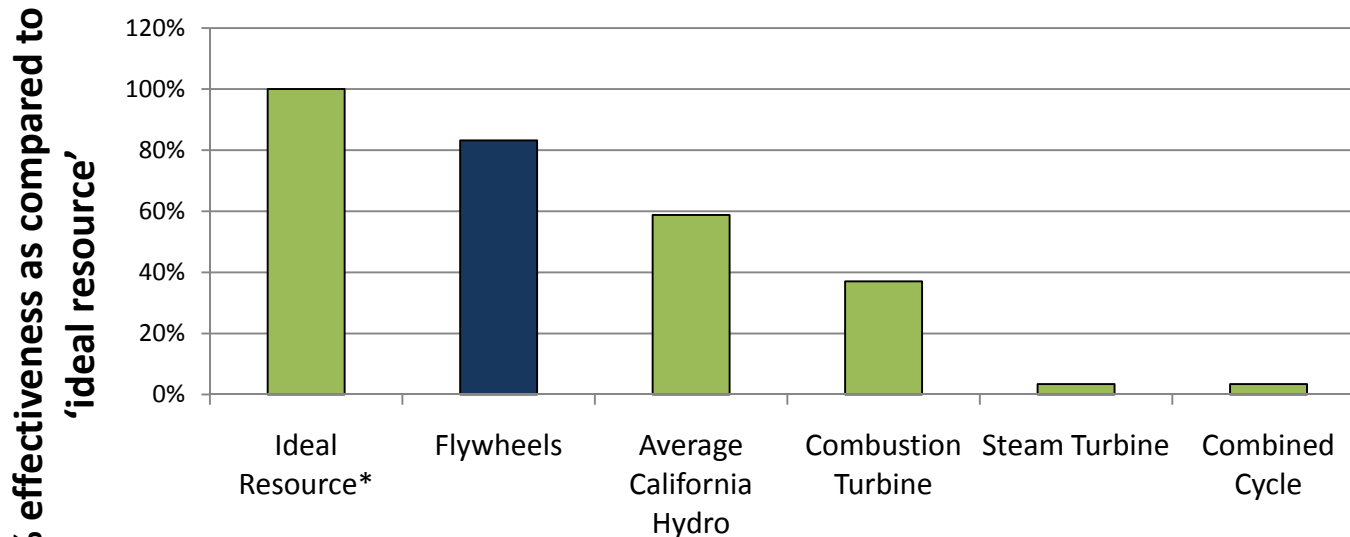
| 1 MW of Regulation |          |           |
|--------------------|----------|-----------|
|                    | Flywheel | Generator |
| ACE Corrected      | 0.48 MWh | 0.18 MWh  |
| Against ACE        | 0 MWh    | -0.07 MWh |
| Net ACE Correction | 0.48 MWh | 0.11 MWh  |

**Faster regulation resources provide more ACE correction per MW offered, can improve control performance and assist in meeting reliability criteria**

# Studies confirm benefits of fast response storage for Regulation

## Regulation Effectiveness: Ability to Correct ACE per MW

As compared to an 'Ideal Resource'



\*An Ideal Resource is defined as one that has instantaneous response and infinite energy

## PNNL Study: Fast response technologies can help reduce the amount of regulation procurement required - Up to 40% in CAISO

\*Source: Makarov, Y.V., et al. "Assessing the value of Regulation Resources Based on Their Time Response Characteristics." Pacific Northwest National Laboratory, PNNL - 17632, June 2008.

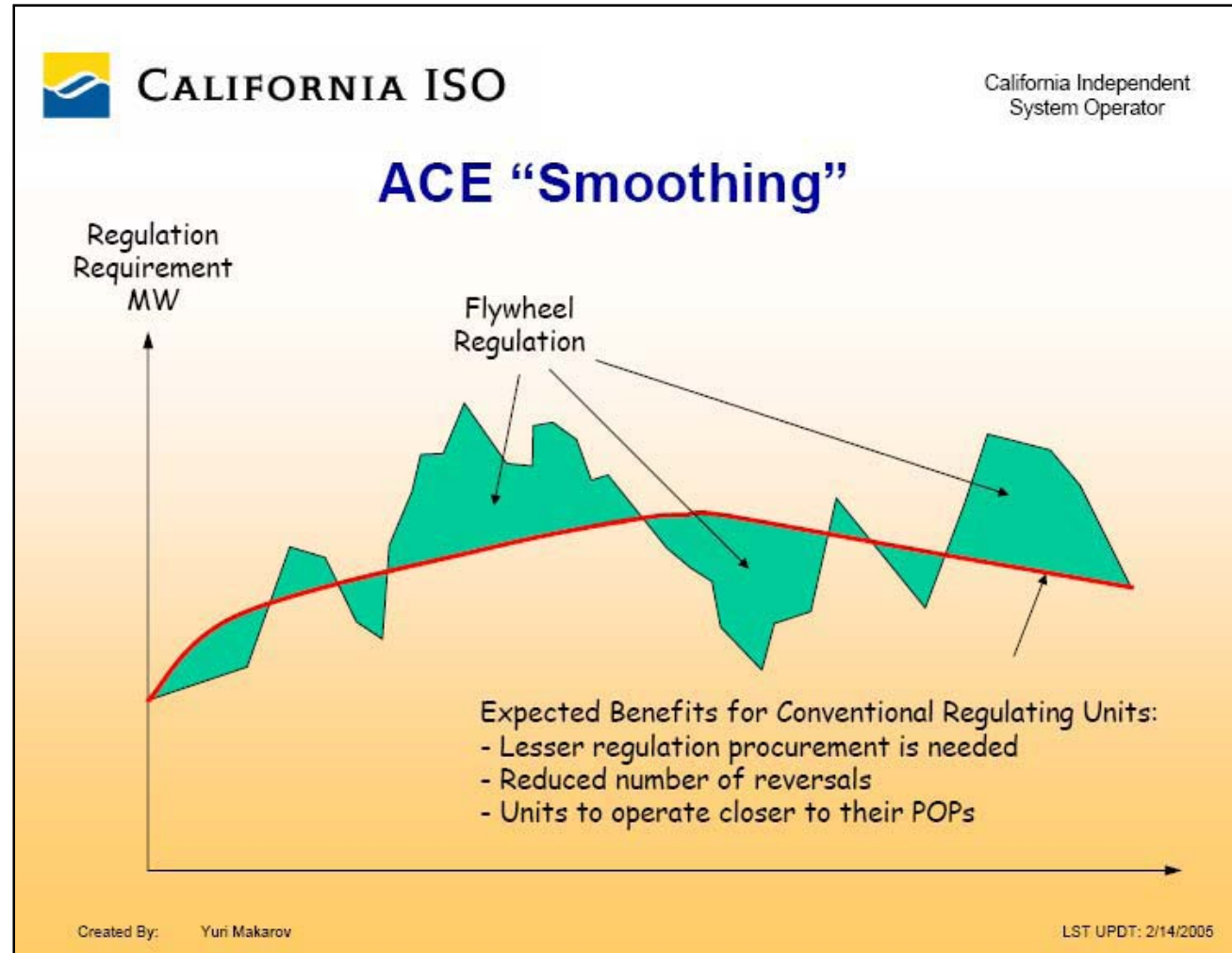
## KEMA Study: "A 30-to-50 MW storage device is as effective or more effective as a 100 MW combustion turbine used for regulation purposes."

Source: "Research Evaluation of Wind Generation, Solar Generation, and Storage Impact on the California Grid," Study by KEMA, Inc., done for California Energy Commission, page 6, June, 2010.



# System Benefits of “Fast First” Regulation

- More effective and tighter control
- Reduces amount of over-control
- Takes advantage of storage ramp capabilities
- Generators can cycle less frequently and operate closer to their preferred operating point
- Less O&M for Generators
- Fewer emissions



# Dispatching based on ramp rate can lower Regulation Procurement



- Deploying regulation resources based on the amount of MWs offered and the resources ramping capability has been demonstrated to lower total regulation procurement & cost to ratepayers

| 2009 Status                                | ISO-NE          | MISO      | PJM       | NYISO     | CAISO      | ERCOT      | ERCOT Proposed |
|--|-----------------|-----------|-----------|-----------|------------|------------|----------------|
| Deployed based on MWs & Ramp               | ✓               | ✓         | N         | N         | N          | N          | N              |
| Deployed based on MWs only                 | N               | N         | ✓         | ✓         | ✓          | ✓          | ✓              |
| Pay-for-Performance                        | ✓               | N         | N         | N         | N          | N          | N              |
| Maximum Allowable Response time            | 5 minutes       | 5 minutes | 5 minutes | 5 minutes | 10 minutes | 10 minutes | 5 minutes      |
| Regulation Procurement (as % of Avg. Load) | 0.66%           | 0.68%     | 1.03%     | 1.17%     | 1.43%      | 1.82%      | 0.91%          |
| Regulation Procurement vs. NE              | 100% (baseline) | 103%      | 156%      | 177%      | 216%       | 277%       | 138%           |

Note: NYISO implemented Fast First Dispatch for energy storage resources, though no such resources were operating in 2009. PJM implemented a Fast signal for energy storage resources, though only 1 MW was operating in 2009.

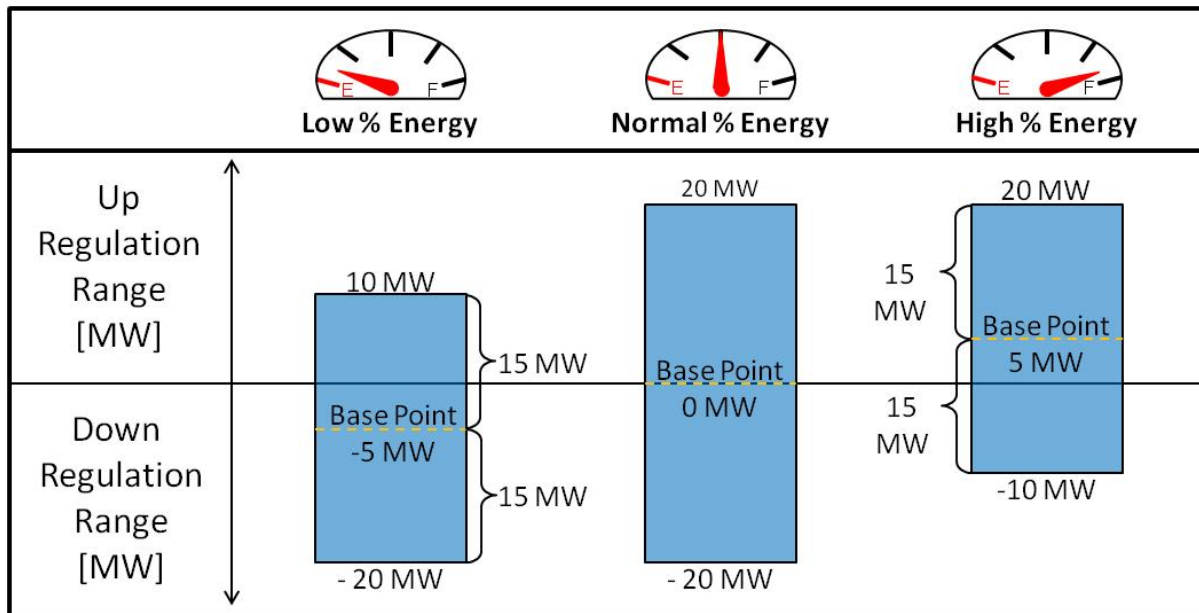
# 1<sup>st</sup> 20 MW Flywheel Regulation Plant Stephentown, NY



- Fall 2008 NYISO developed market rule revisions to integrate storage into its Regulation market
- Spring 2009 FERC approved NYISO's market rule revisions
- Summer 2009 Awarded DOE Loan Guarantee commitment
- Fall 2009 NY PSC approved project, start of construction
- Fall 2010 First 4 MW on-line providing Regulation
- Spring 2011 Expected project completion

# NYISO/MISO: Market rule revisions for Limited Energy Storage Resources

- Created new Energy Storage resource category
- Changed dispatch to use fast response storage first
- New Net Energy Settlement Provision for storage
  - Hourly Energy Settlement = (Injections – Withdrawals) \* LMP
- ISO utilizing 5-minute energy market to schedule energy into/out of the storage to maintain stored energy level, maintain maximum regulation
  - Normally the system can provide full regulation in both directions
  - When empty provide “Up Reg” like DR; when full provide “Down Reg” like Generator

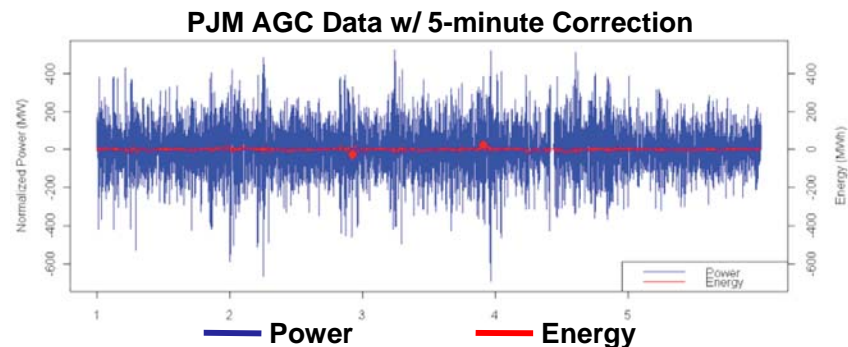
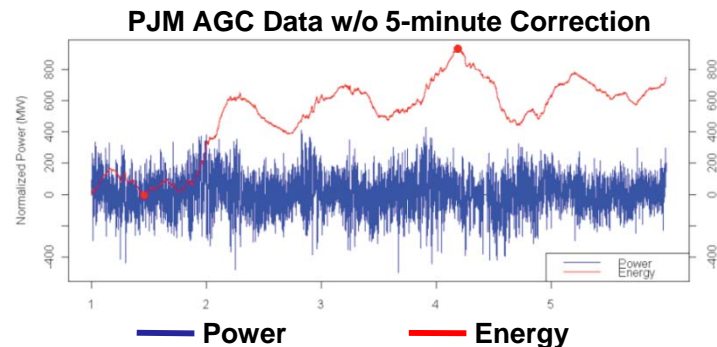


# EPRI Study of Regulation by Limited Energy Storage Resources

- EPRI confirmed that a 15 minute energy storage device can continuously provide regulation if it has a mechanism to manage its energy level (i.e. state-of-charge)
- Five minute energy market enables storage to manage its energy
- Confirmed benefits of the “NYISO/MISO” methodology

## Results:

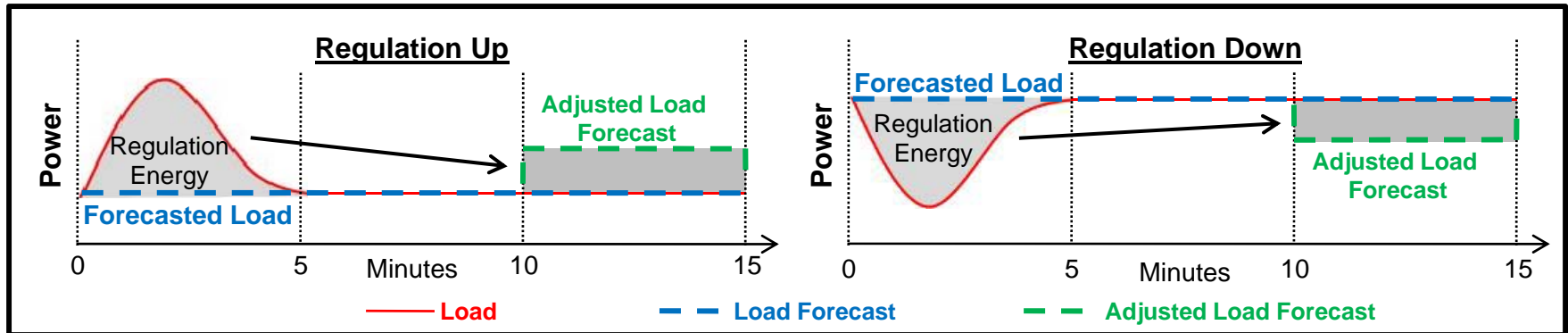
- Regulation can have a significant energy bias (this data set had a maximum bias of 929 MWh over 1 week)



- Utilizing a 5-minute correction (purchase or sale of energy) dramatically reduces the amount of energy storage capacity required to provide regulation (in this example reduced required storage from 2.1 hours to 3 minutes)

**EPRI study showed 15 minute energy storage can continuously provide Regulation**

# Using Storage = Smart Load Following



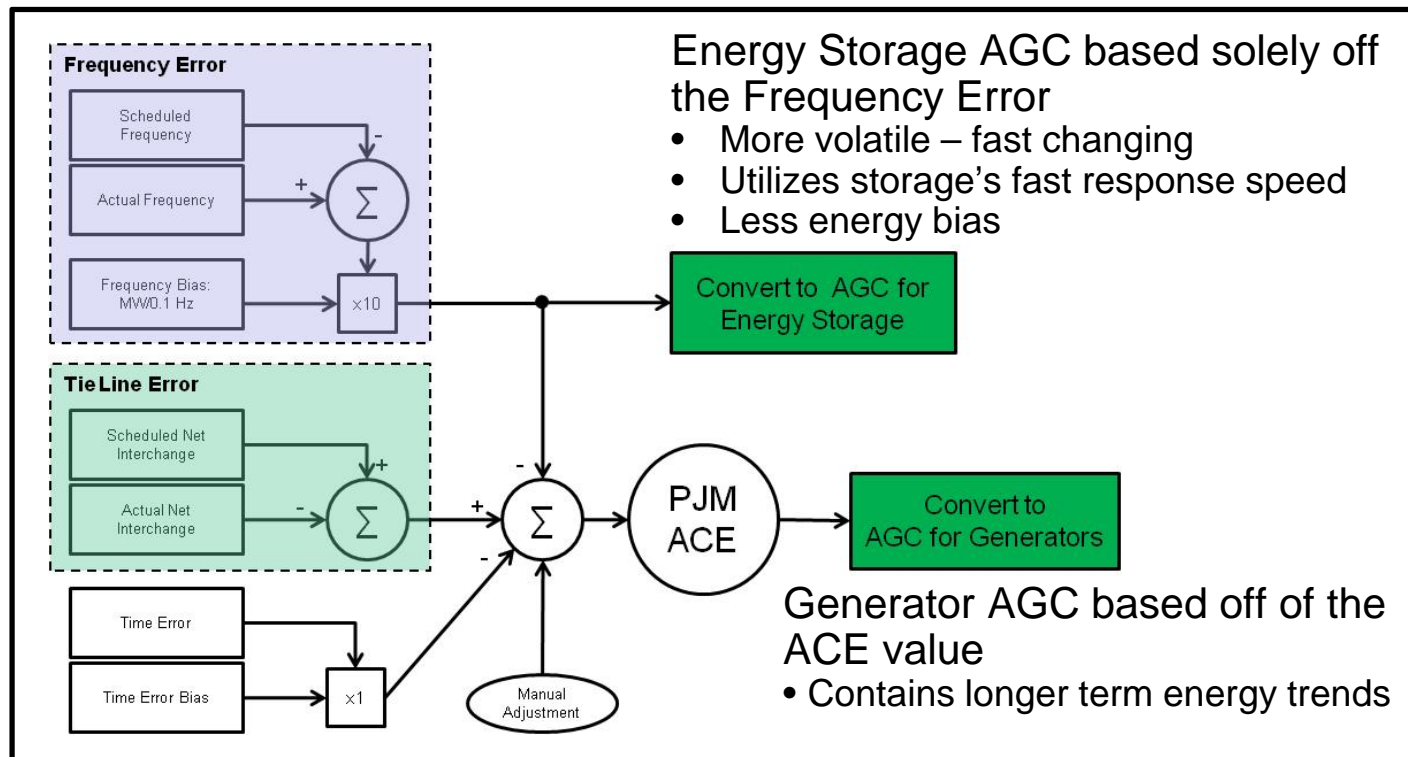
|                 | Interval 1               | Interval 2   | Interval 3  |
|-----------------|--------------------------|--|---|
| Regulation Up   | Storage injects energy   | If storage nearing empty, ISO schedules storage to “charge” and adjusts Interval 3 load forecast | ISO procures the energy necessary to meet new forecast in energy market on most economic resource       |
| Regulation Down | Storage withdraws energy | If storage filling up, ISO schedules storage to “discharge” in interval 3                        | Storage injects recycled energy as price taker, displacing deployment on marginal unit in energy market |

- Fast response storage instantaneously responds to imbalance; energy used to restore storage to its preferred state-of-charge can be economically scheduled
- Energy management results in sending the right energy market price signal

**NYISO/MISO Energy Management = “Smart Load Following”**

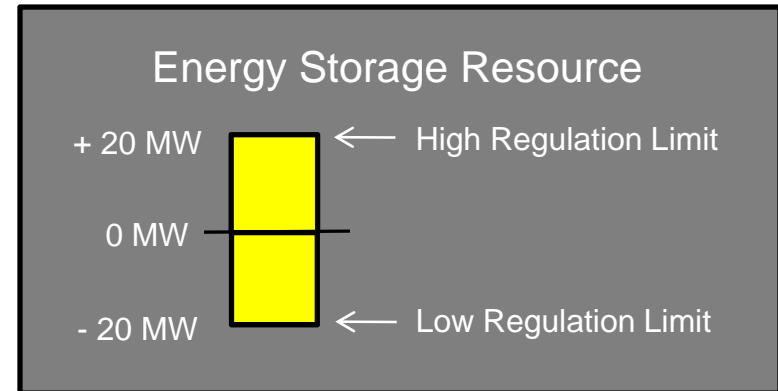
# PJM Fast “Frequency” Based Signal for Storage

- PJM developed a new ‘frequency-based’ AGC for storage devices; that is unfiltered and does not include tie-line error
- PJM allows storage to self manage its energy base point and capacity in real time under existing market rules



# Enable Storage to model its operating characteristics

- Generation and Load Regulation Dispatch Limits do not work well for energy storage
  - Operating Limits: +/- 20 MW around 0 MW base-point
  - Must be able to model positive (injections) and negative (withdrawals)
- Resource Regulation ramp rate derived from capacity. Calculation is problematic for fast resources.
  - Ramp Rate = Regulation Capacity/5 min
  - For a 20 MW flywheel plant implies a ramp rate of 4 MW/min
  - Actual Flywheel Ramp Rate = 300 MW/min
    - *Fully deployed +/-20MW in 4 seconds*



**Recommend creating an Energy Storage asset category**



- Advanced storage provides wholesale Regulation Service by storing and then injecting power to the grid at a later time in response to an AGC signal
  - In other ISOs FERC has found that energy used for pumping at pumped storage facilities and used for charging advanced energy storage resources should be excluded from retail rates because such energy is stored for later wholesale delivery
- Energy storage resources must be able to settle net energy at wholesale
- Recommend include energy settlement formula in rules:
  - Energy Settlement = (Injections – Withdrawals) \* LMP

# Integration of Storage in ERCOT



- Beacon looks forward to working with the Power Storage Working Group to remove barriers and integrate storage into ERCOT's markets

| Challenge/Barrier   | Recommendations   |
|---|---|
| A/S definition requires 60 minutes of energy                        | <ul style="list-style-type: none"><li>• Allow storage to utilize energy market to manage its stored energy level, i.e. "state of charge"</li></ul>  |
| Cannot model operational characteristics                            | <ul style="list-style-type: none"><li>• Enable storage to model as a positive/negative resource that operates around a 0 MW base point</li></ul>  |
| Regulation Signal designed for slow ramping resources               | <ul style="list-style-type: none"><li>• Allow resources to provide full ramp rate</li><li>• Dispatch "Fast first" to take advantage of fast response capability</li><li>• Compensate regulation resources based on performance to encourage faster ramping from all resources</li></ul> |
| Protocols not designed for regulation resources that recycle energy | <ul style="list-style-type: none"><li>• Create a new energy storage resource category</li><li>• Allow storage to settle its net energy usage at the wholesale rate</li></ul>  |

# Smart Grid of the Future



*Zero-emissions storage-based regulation... is a better performing, more cost-effective resource... a Smart Grid match for clean wind generation...*



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