

20 MW Flywheel Energy Storage Plant

Case Study for the:

Advanced Energy 2010 Conference

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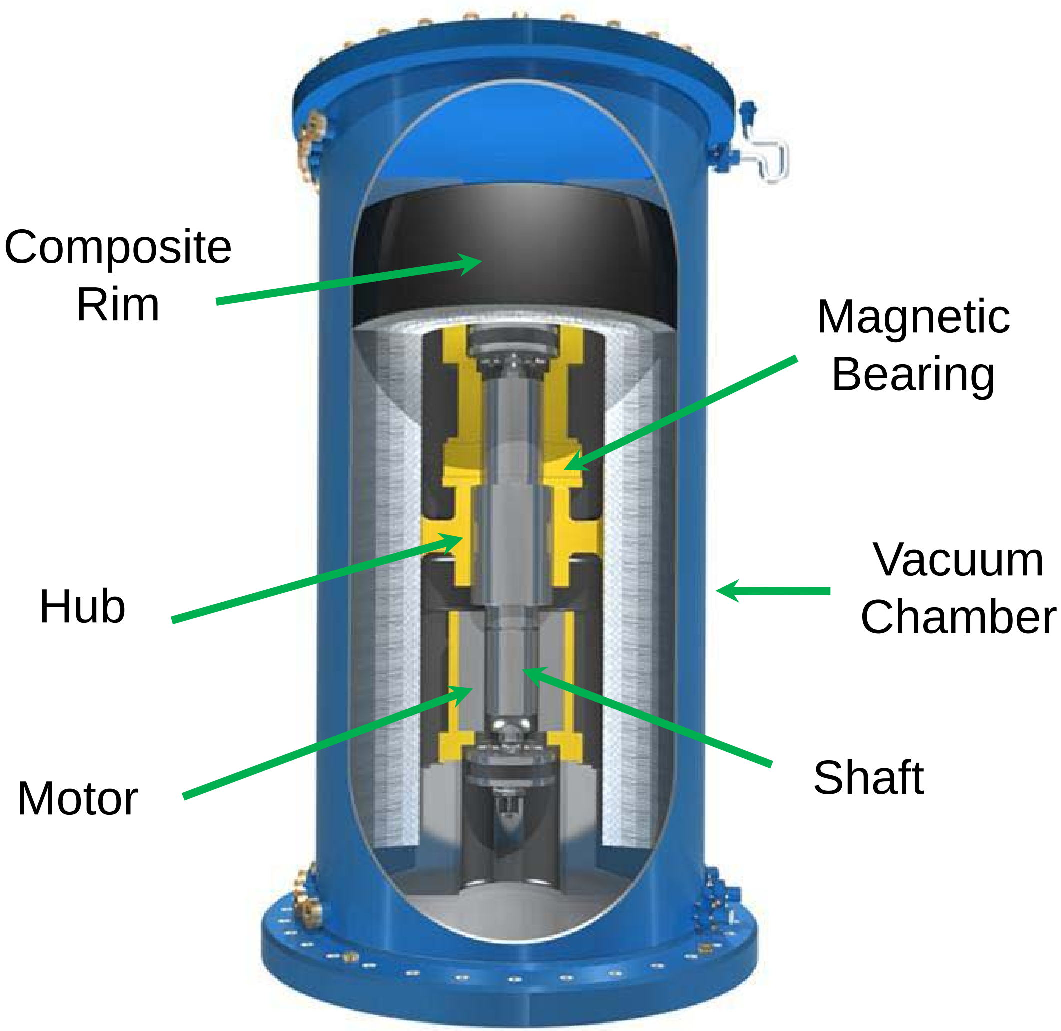
Company Overview

- We provide flywheel-based frequency regulation to utility industry as a:
  - Merchant service provider
  - Seller of turnkey plants
- Operating in ISO-NE since Nov. 2008
- 60 MW under development (merchant)
  - $43M DOE loan guarantee
  - $24M DOE stimulus grant
  - Pennsylvania has budgeted $5M grant for a 20 MW flywheel plant
- $2.25M DOE ARPA-E grant award to develop a 1-hr. flywheel for wind and solar ramping, peak demand limiting

20 MW plant in Stephentown, NY

Technology



- Up to 17 times better than fossil generators
- Zero energy storage degradation
- 20-year design life
- 125,000 equivalent cycles
- Zero emissions
- Available à la carte
- Low operating cost

1 MW / 250 kWh Module

- Ten 100kW / 25 kWh flywheels
- Transformers and support equipment
- Electronics and controls inside container

1st 20 MW Flywheel Regulation Plant
NYISO – New York Grid Operator

- Stephentown, NY
- Broke ground Nov 2009
- Matching equity raised Dec 09
- $43M DOE loan guarantee closed Aug 2010
- Interconnection agreement signed
- First revenue Q4 2010
- Full capacity Q1 2011

NY-ISO and NY PSC participated in groundbreaking

Gen 4 Flywheel in Production

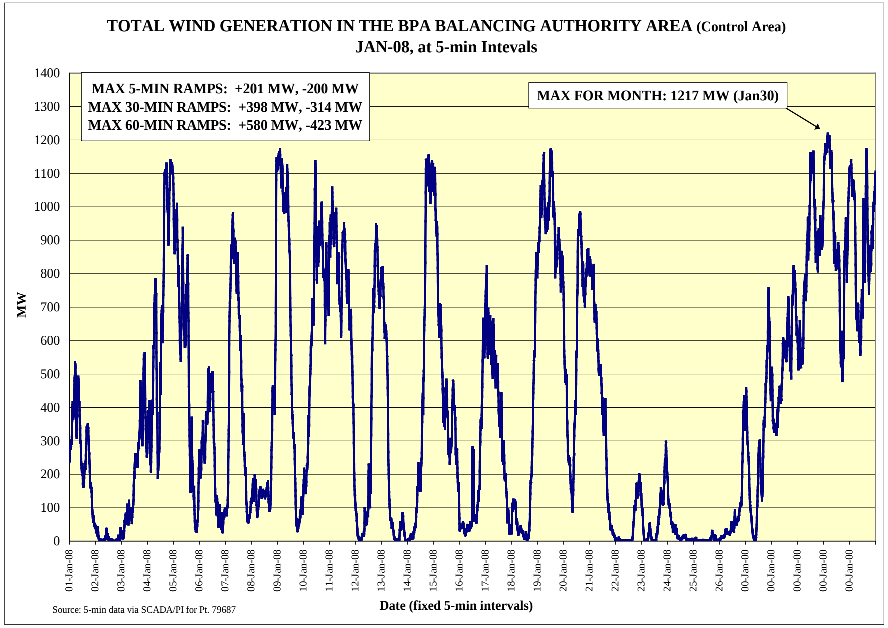
Ramping Up Production

Construction Underway

On Time and On Budget

Renewables Increase Regulation Need

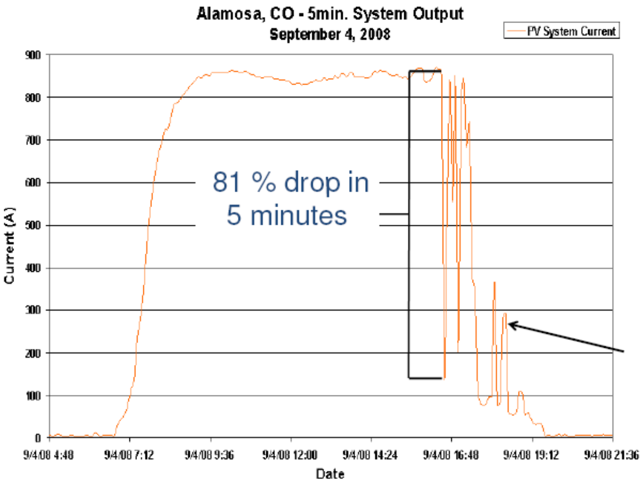
Wind Ramping



31 days

Solar Shading

Solar energy sources are highly variable



Output from an 8MW solar PV panel in Colorado on 9/4/08

High variability due to clouds

16 hours

Impact of 20% Wind Penetration in Eastern Interconnection

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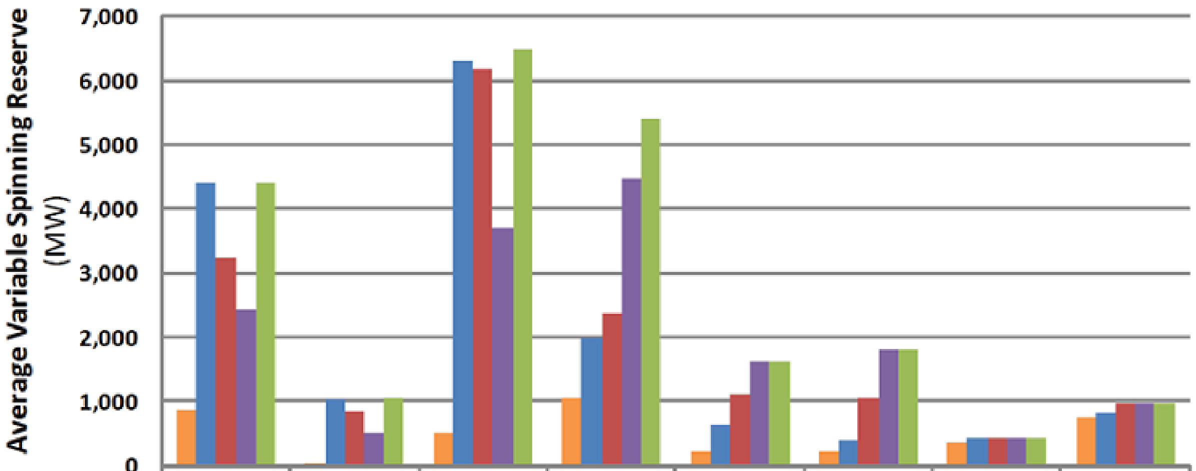

	MISO	MAPP	SPP	PJM	NYISO	ISO-NE	TVA	SERC
Load Only	885	43	514	1055	217	202	365	741
Actual Wind S1	4,424	1,020	6,308	1,994	618	399	420	816
Actual Wind S2	3,245	835	6,176	2,359	1,118	1,046	418	955
Actual Wind S3	2,419	503	3,695	4,463	1,614	1,789	418	955
Actual Wind S4	4,423	1,038	6,487	5,410	1,614	1,789	418	955

Region

"Load Only" is today's regulation requirement

Scenarios 1,2,3 show different mixes of on-shore, off-shore and regional mixes for 20% wind penetration

Scenario 4 is 30% wind penetration

For 20% wind penetration, the average increase in forecasted need for regulation resources is several hundred percent…

Source: EASTERN WIND INTEGRATION AND TRANSMISSION STUDY, January 2010 Prepared for NREL by: EnerNex Corporation Knoxville, Tennessee, NREL Technical Monitor: David Corbus, Prepared under Subcontract No. AAM-8-88513-01

NY ISO Forecasts Regulation Needs

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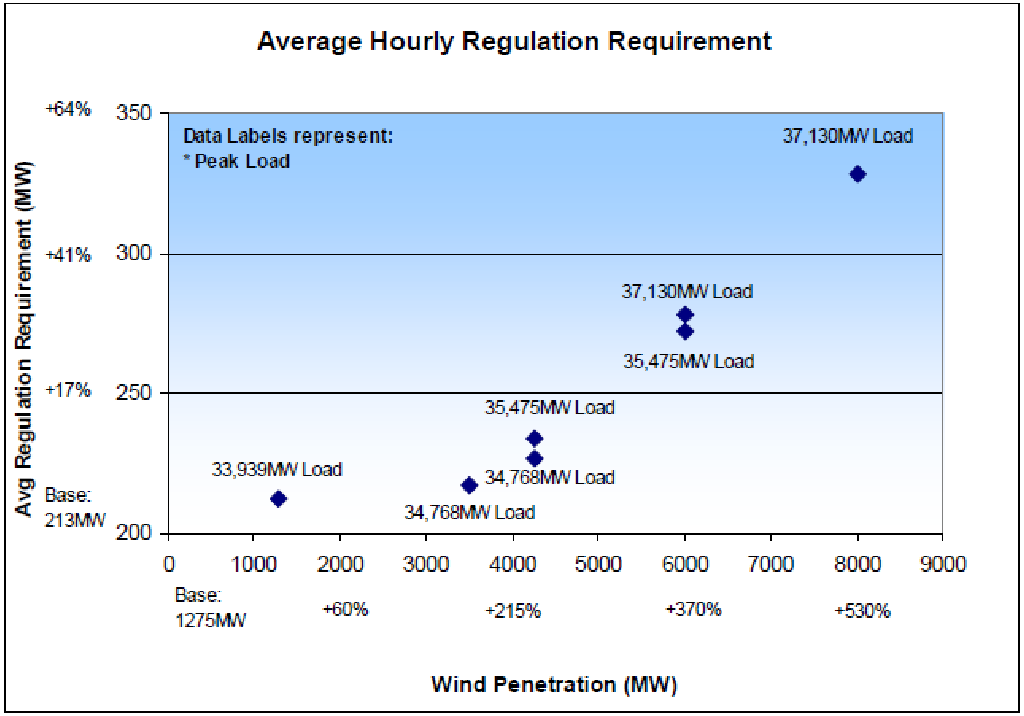
NEW YORK INDEPENDENT SYSTEM OPERATOR

Regulation Req. vs. Wind Level

- As shown in the graph below, the average regulation requirement increases approximately 9% for every 1,000MW increase between the 4,250MW and 8,000MW wind penetration level.



Requirement increases by 60% with 10% wind

Benefits of Fast Regulation

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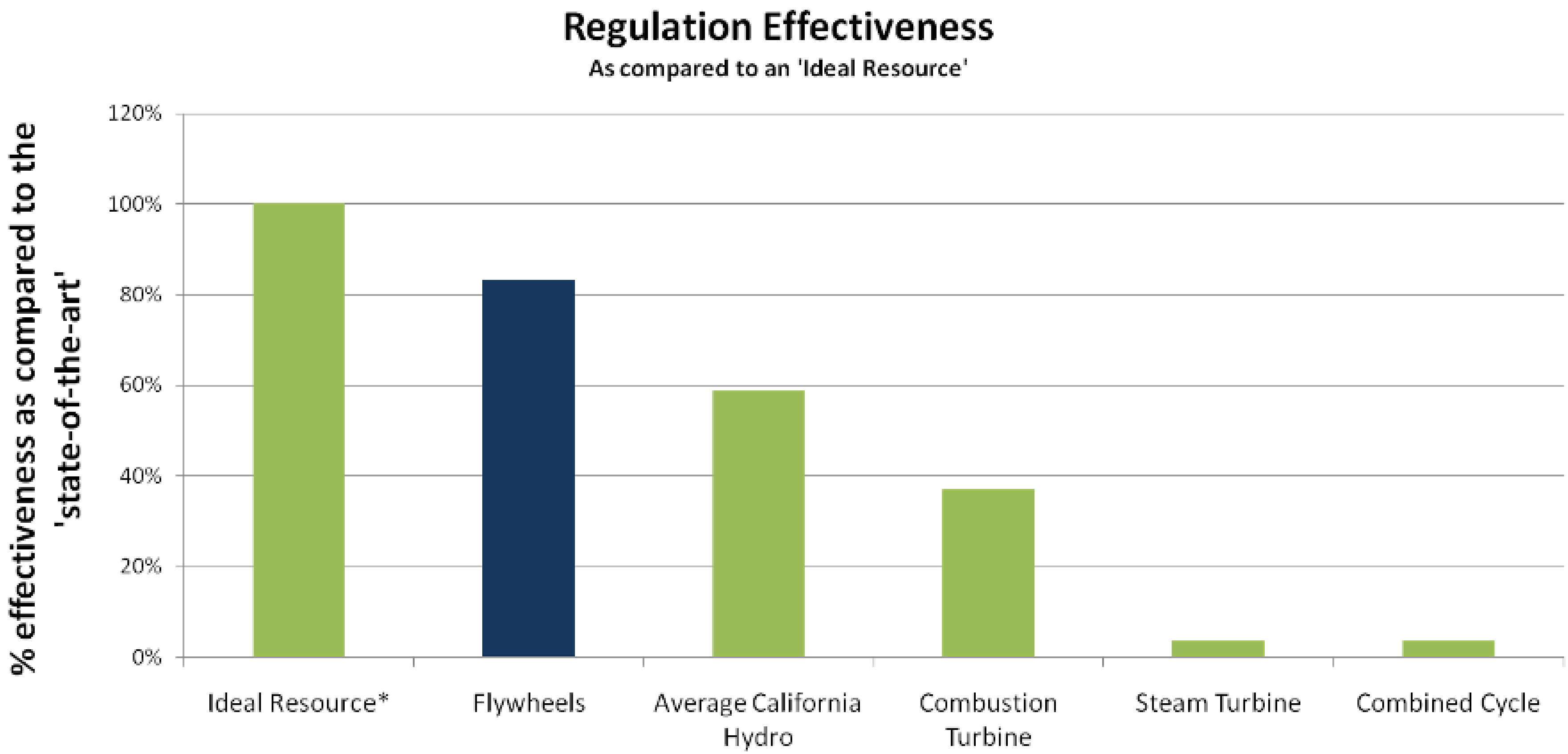
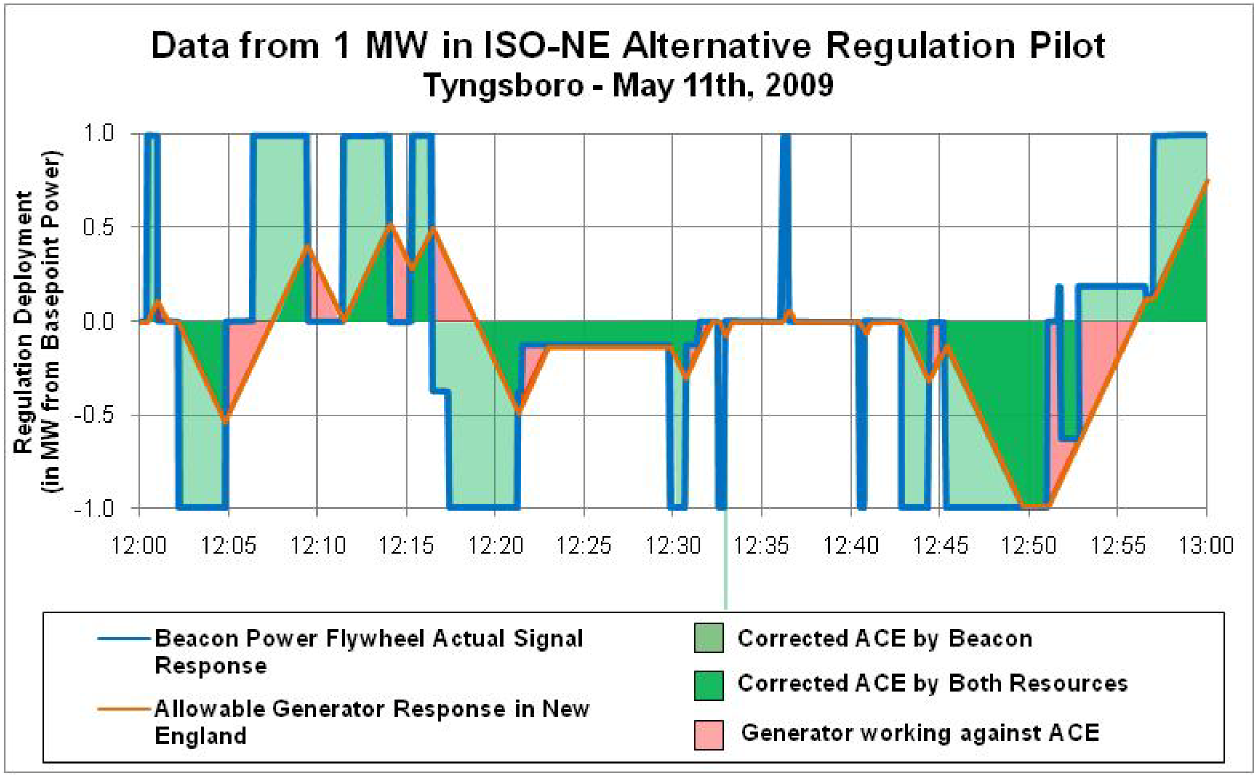


Fast response flywheels 2 to 17 times more effective than slow resources

*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

ISO-NE Pilot Program Empirical Data

- Flywheels 4x better at meeting regulation requirements

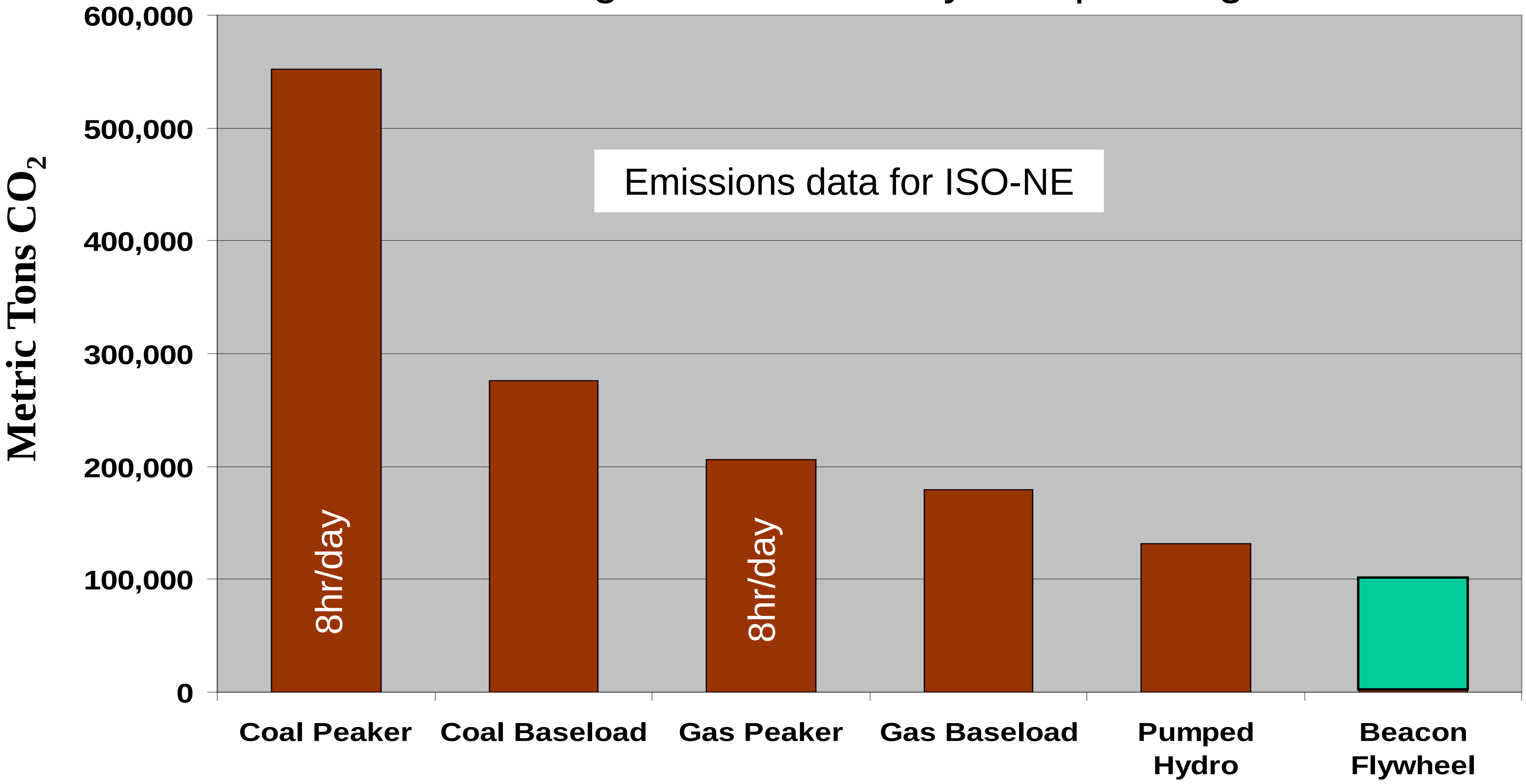


	1 MW of Regulation	
	Flywheel	**Generator**
ACE Corrected	**0.48 MWh**	**0.18 MWh**
Against ACE	**0 MWh**	**-0.07 MWh**
Net ACE Correction	**0.48 MWh**	**0.11 MWh**
Mileage	**25 “MW-miles”**	**8 “MW-miles”**

ISO-NE’s mileage payment (sum of up and down movement) pays resources for providing more regulation service to the grid

Lower CO_2 Emissions

Source: KEMA study: CO_2 Reduction for 20 MW of Storage-based Regulation over 20-year operating life



Flywheel regulation has zero direct CO_2 emissions

FERC Supports "Pay for Performance"

- Testimony before the Senate Energy Committee by FERC Chairman Jon Wellinghoff, December 10, 2009:

  "Regarding compensation, some storage technologies appear able to provide a nearly instantaneous response to regulation signals, in a manner that is also more accurate than conventional resources. These two characteristics can reduce the size and hence overall expense, of the regulation market. Most existing tariffs or markets do not compensate resources for superior speed or accuracy of regulation response, *but such payment may be appropriate in the future* [ ]."

FERC Commissioner Philip D. Moeller visits Beacon Power on December 10, 2009

Paying for Speed = Ratepayer Benefits

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Traditional Regulation method *Same signal all resources*						"Fast first" method *Dispatch and Pay based on Response Speed*							
Ramp Rate	RCP	Awarded Reg	Reg Service	Total Payment	$/MW	Ramp Rate	RCP	Awarded Reg	Reg Service	Reg Payment	Service Payment	Total Payment	$/MW
Average	$36	20 MW	200 MW	$720	$36	Average	$18	20 MW	**200 MW**	$360	$360	$720	$36
Average	$36	20 MW	200 MW	$720	$36	Average	$18	20 MW	**200 MW**	$360	$360	$720	$36
Fast	$36	20 MW	200 MW	$720	$36	Fast	$18	20 MW	**600 MW**	$360	$1,080	$1,440	$72
Slow	$36	20 MW	200 MW	$720	$36	~~Slow~~	~~$18~~	~~20 MW~~	~~**0 MW**~~	~~$360~~	~~$0~~	~~$360~~	~~$18~~
Slow	$36	20 MW	200 MW	$720	$36	~~Slow~~	~~$18~~	~~20 MW~~	~~**0 MW**~~	~~$360~~	~~$0~~	~~$360~~	~~$18~~
Total Market	**$36**	**100 MW**	**1,000 MW**	**$3,600**	**$36**	**Total Market**	**$18**	**60 MW**	**1,000 MW**	**$1,080**	**$1,800**	**$2,880**	**$48**
												20% savings	

"Fast First" method results in same Regulation effectiveness with less overall cost for ratepayers

Example: 20% savings in cost, 40% savings in MWs procured

Frees Up 40 MW of capacity to provide energy or other reserves

Flywheels vs. Batteries

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	Flywheels	Batteries	Comment
Equivalent charge/discharge cycles	125,000	?	8,760 equivalent charge / discharge cycles/yr. needed in New York State for storage-based regulation
Design life	20+ years	?	EPRI survey shows that utilities want 15-year minimum equipment life
Energy storage capacity degradation	Zero	?	Battery systems must be refreshed / replaced

- Batteries will be challenged by high cyclic demand of storage-based tariffs
- Initial capital cost of batteries will be a fraction of total lifetime CapX costs
- Project financing for batteries may be harder (replacement costs uncertain)
- Batteries may be less attractive to vertical utilities whose return on equity is based on initial capital cost (operating cost is a “pass through” expense)

ISO-NE Cyclic Content

$$\boldsymbol{Annual\ equivalent\ cycles} = \frac{\boldsymbol{annual\ injected\ energy}}{\boldsymbol{storage\ capacity}}$$

- Rated Power: 1MW
- Storage Capacity: 0.25 MWh / cycle
- Measured injection of energy into grid: 1,575 MWh / year
- Regulation plant life: 20 years

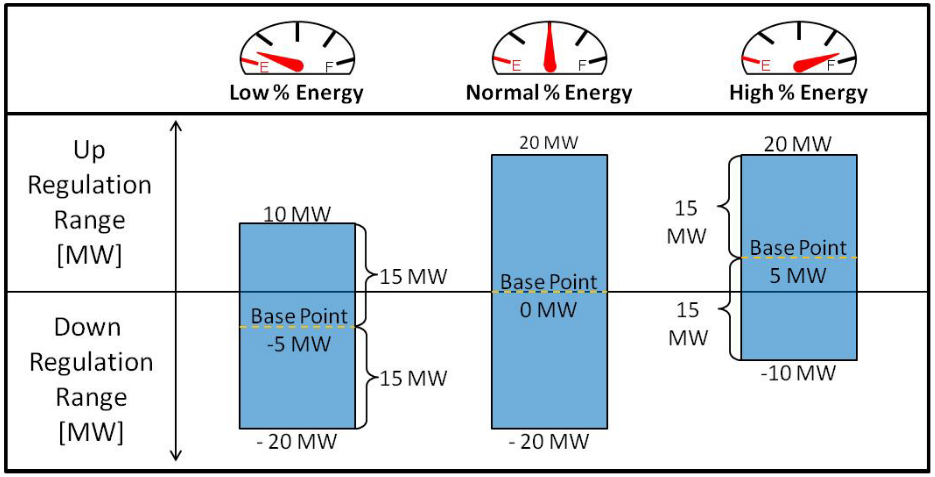
Annual equivalent cycles $= \dfrac{1{,}575}{0.25} =$ 6,300 cycles / year

Historical data from Beacon Power's operation of 3 MWs under ISO-NE Pilot Program regulation dispatch algorithm

~ 125,000 cycles in 20 years

Key Elements: Market Rules for Limited Energy Storage Resources

- Create Energy Storage resource category
- Allow to provide Regulation Service only
- Utilizes storage's fast ramping capability
- Net Energy Settlement provision for storage
  - Hourly Energy Settlement = (Injections – Withdrawals) * LMP
- Enable storage to utilize 5-minute energy market to schedule energy into/out of the resource to maintain stored energy level ("state-of-charge")
  - Normally the system can provide full regulation in both directions
  - When empty provide "Up Reg" like DR; when full provide "Down Reg" like Generator



NYISO Regulation Control Algorithm

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Figure 4: LESR Regulation Deployments

(1) LESR is not storage constrained	AGC allocates maximum ACE to the LESR assuming no regulation ramp rate constraints
(2) LESR is approaching a maximum storage limitation	(a) AGC will allocate +ACE to an LESR constrained by the unit regulation response rate
	(b) AGC will allocate -ACE to the maximum accepted capability of the LESR without ramp constraints
(3) LESR has reached the maximum storage limitation	(a) When this condition is reached, +ACE will not be allocated for the remainder of the RTD interval
	(b) AGC will allocate – ACE to the maximum accepted capability of the LESR without ramp constraints
(4) LESR is approaching the minimum storage limitation	(a) AGC will allocate -ACE to an LESR constraining the allocation by the unit regulation response rate
	(b) AGC will allocate +ACE to the maximum accepted capability of the LESR without ramp constraints
(5) LESR has reached the minimum storage limitation	(a) When this condition is reached, -ACE will not be allocated for the rest of the RTD interval.
	(b) AGC will allocate + ACE to the maximum accepted capability of the LESR without ramp constraints

NYISO Area Control Error (Historical)

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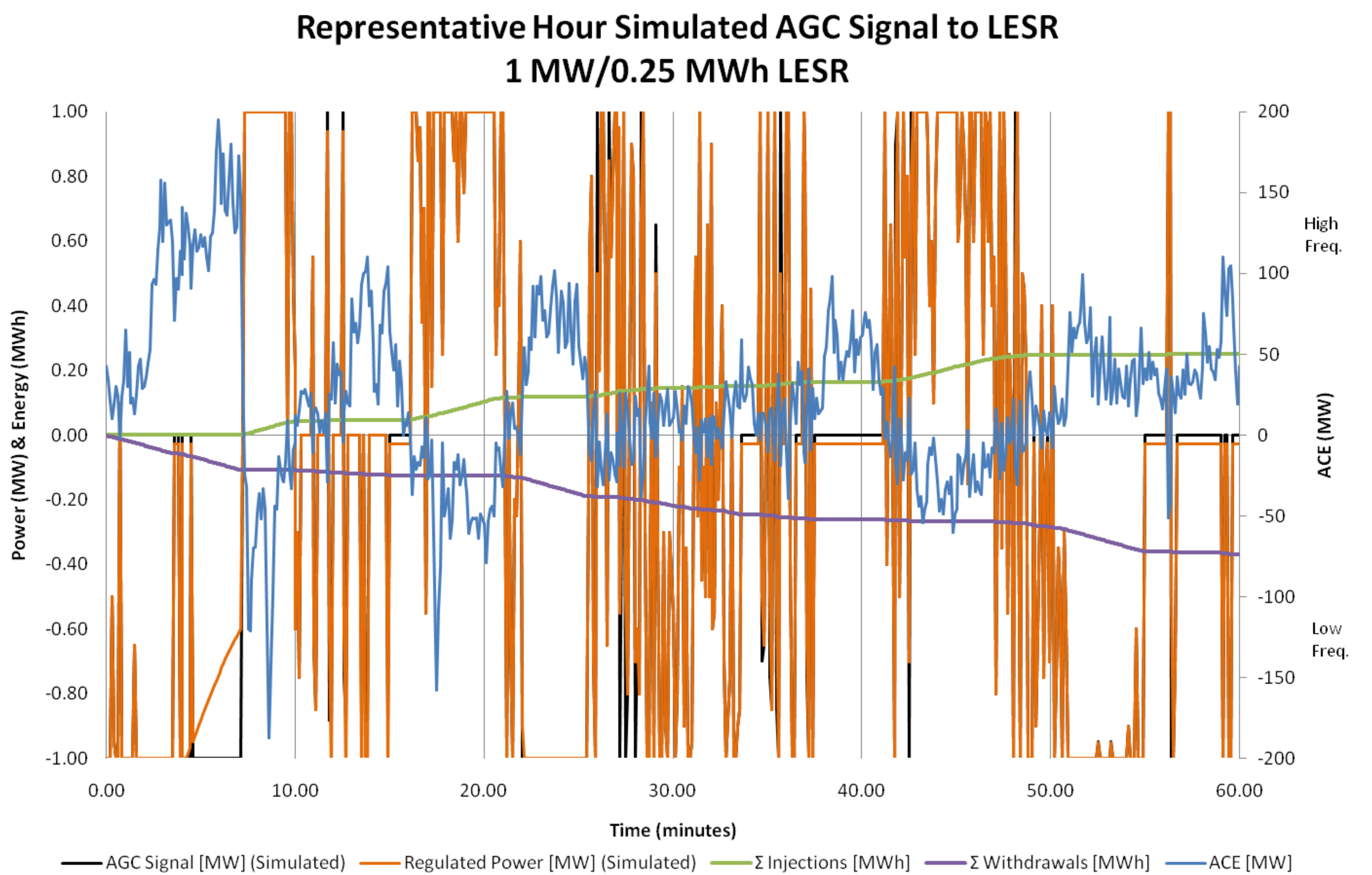
Time [mins]	ACE [MW]	AGC Signal [MW] (Simulated)	Regulated Power [MW] (Simulated)	Σ Injections [MWh]	Σ Withdrawals [MWh]
0.00	43.00	-1.00	-1.00	0.00	0.00
0.10	34.00	-1.00	-1.00	0.00	0.00
0.20	21.00	-1.00	-1.00	0.00	-0.01
0.30	10.00	-0.50	-0.50	0.00	-0.01
0.40	19.00	-0.95	-0.95	0.00	-0.01
0.50	30.00	-1.00	-1.00	0.00	-0.01
0.60	24.00	-1.00	-1.00	0.00	-0.01
0.70	-2.00	0.10	0.10	0.00	-0.01
0.80	24.00	-1.00	-1.00	0.00	-0.01
0.90	34.00	-1.00	-1.00	0.00	-0.01
1.00	65.00	-1.00	-1.00	0.00	-0.02
1.10	30.00	-1.00	-1.00	0.00	-0.02
1.20	51.00	-1.00	-1.00	0.00	-0.02
1.30	20.00	-1.00	-1.00	0.00	-0.02
1.40	23.00	-1.00	-1.00	0.00	-0.02
1.50	13.00	-0.65	-0.65	0.00	-0.02
1.60	25.00	-1.00	-1.00	0.00	-0.03
1.70	43.00	-1.00	-1.00	0.00	-0.03
1.80	47.00	-1.00	-1.00	0.00	-0.03
1.90	29.00	-1.00	-1.00	0.00	-0.03
2.00	30.00	-1.00	-1.00	0.00	-0.03
2.10	36.00	-1.00	-1.00	0.00	-0.03
2.20	45.00	-1.00	-1.00	0.00	-0.04
2.30	53.00	-1.00	-1.00	0.00	-0.04
2.40	93.00	-1.00	-1.00	0.00	-0.04
2.50	96.00	-1.00	-1.00	0.00	-0.04
2.60	93.00	-1.00	-1.00	0.00	-0.04
2.70	115.00	-1.00	-1.00	0.00	-0.04
2.80	129.00	-1.00	-1.00	0.00	-0.05
2.90	158.00	-1.00	-1.00	0.00	-0.05
3.00	120.00	-1.00	-1.00	0.00	-0.05
3.10	156.00	-1.00	-1.00	0.00	-0.05
3.20	130.00	-1.00	-1.00	0.00	-0.05
3.30	132.00	-1.00	-1.00	0.00	-0.05

NYISO Cyclic Content Simulation



1 Hour Data Summary:

Injections = 0.25 MWh Withdrawals = 0.37 MWh

≈ 24 "Throughput cycles per day"

NYISO Cyclic Content Calculation

$$\boldsymbol{Annual\ equivalent\ cycles = \frac{annual\ injected\ energy}{storage\ capacity}}$$

- Rated Power: 1MW
- Storage Capacity: 0.25 MWh / cycle
- Measured injection of energy into grid: 2,190 MWh / year
- Regulation plant life: 20 years

Annual equivalent cycles = $\frac{2{,}190}{0.25}$ = 8,760 cycles / year

NYISO's regulation dispatch algorithm will be even more demanding than ISO-NE's Pilot Program…

~ 175,000 cycles in 20 years

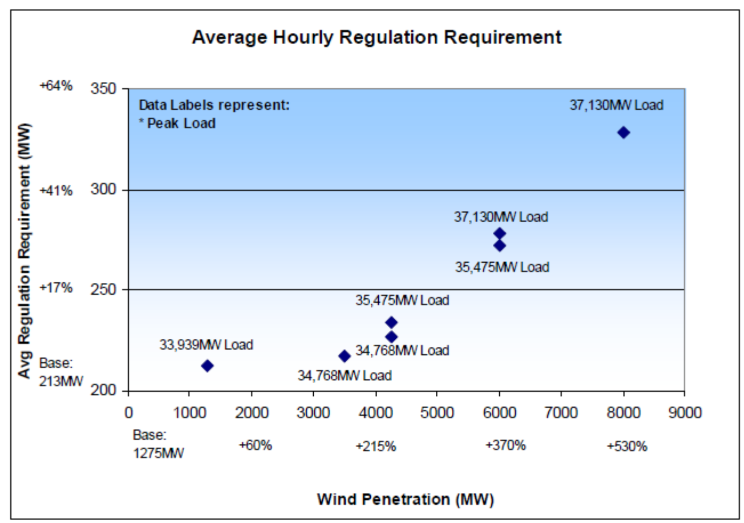
Frequency Regulation of the Future

Adding wind creates the need for more regulation capacity…

NEW YORK INDEPENDENT SYSTEM OPERATOR

Regulation Req. vs. Wind Level

- **As shown in the graph below, the average regulation requirement increases approximately 9% for every 1,000MW increase between the 4,250MW and 8,000MW wind penetration level.**



Frequency Regulation of the Future?

We want to integrate more wind, but does this really make sense?

Frequency Regulation of the Future

Zero-emissions storage-based regulation is a better performing, more cost-effective resource… an ideal match for clean renewable energy…

Thank You!

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