DOE Energy Storage Systems Research Program Annual Peer Review

November 2-3
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Flywheel-based Frequency Regulation Demonstration Projects for CEC, NYSERDA, & DOE

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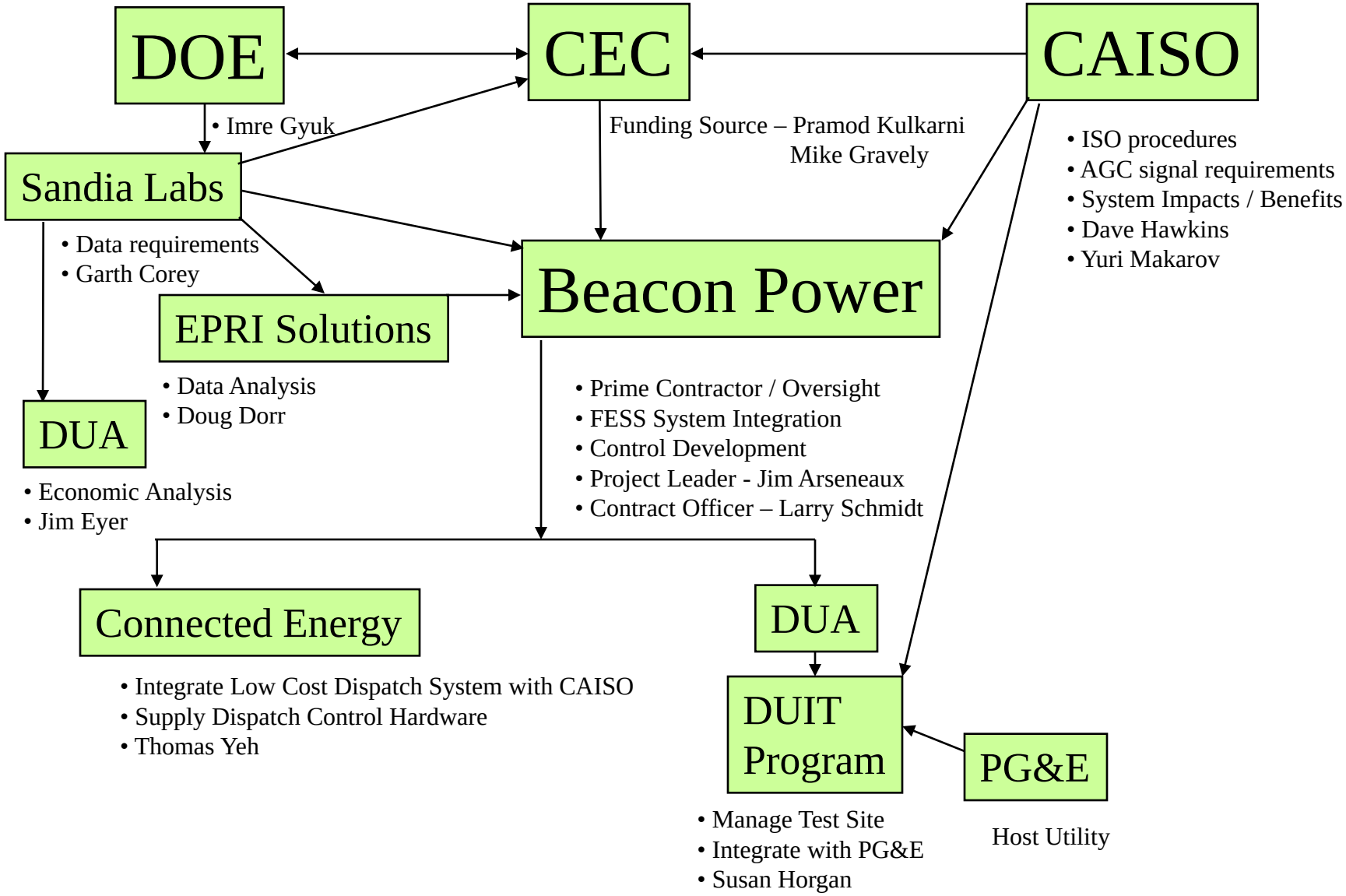
Objectives of Demonstration Projects

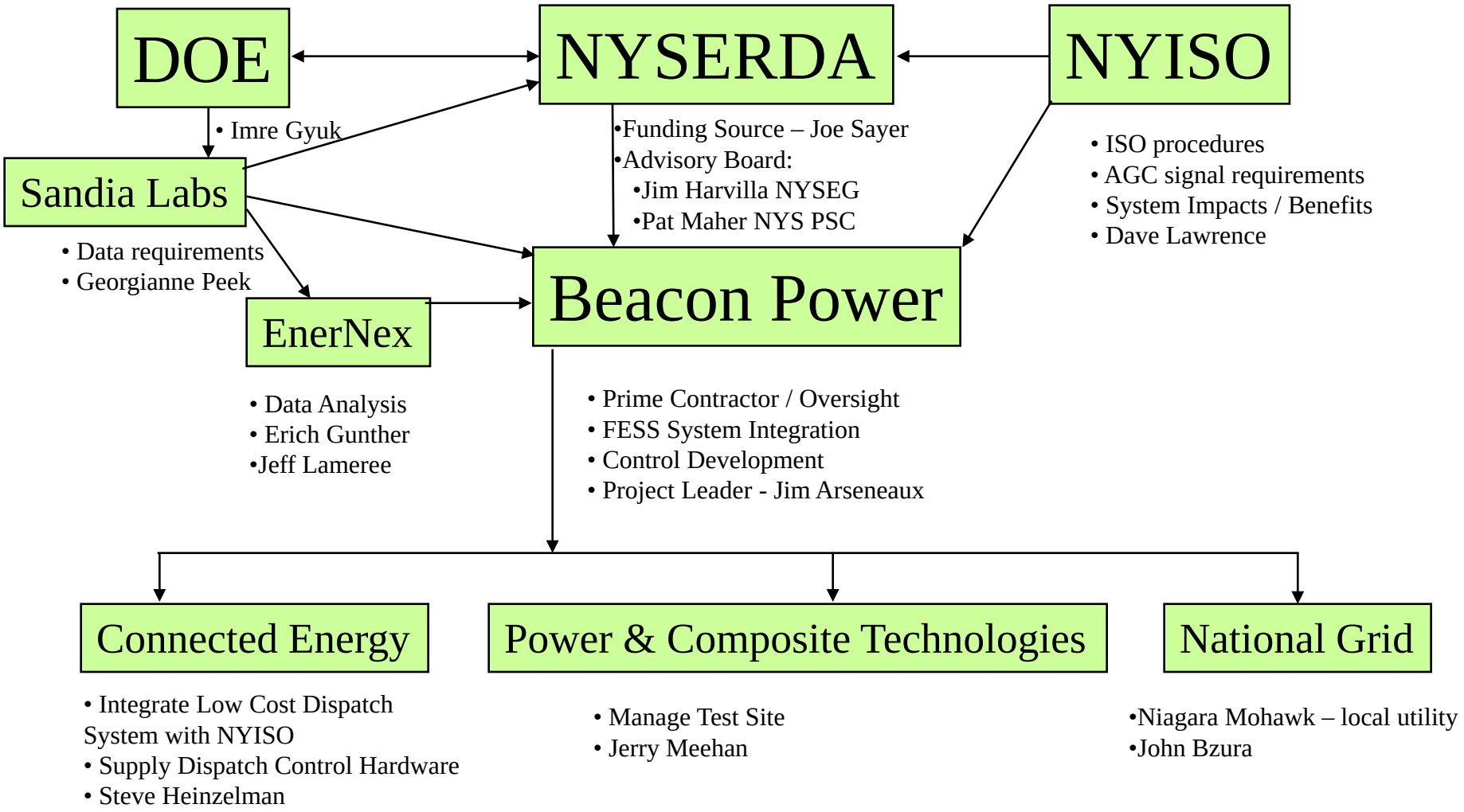
- Proof of concept on ~1/10th power scale
- Show ability to follow fast-changing frequency regulation signals
- Demonstrate anti-islanding
- Validate interconnection capability

  (NYSERDA on end of line - CEC at substation)
- Demonstrate performance and economic value
- Develop and demonstrate communications with grid operators
- Demonstrate reactive power compensation (NYSERDA only)
- Collect data for product specifications
- Gain industry confidence
- Report results to the industry

CEC Project Team

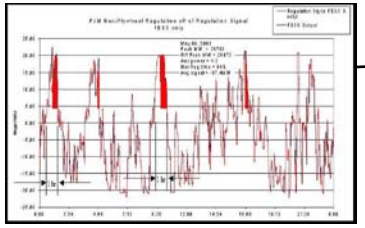


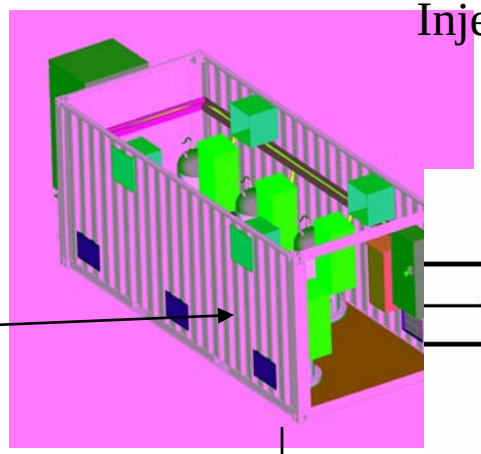
NYSERDA Project Team



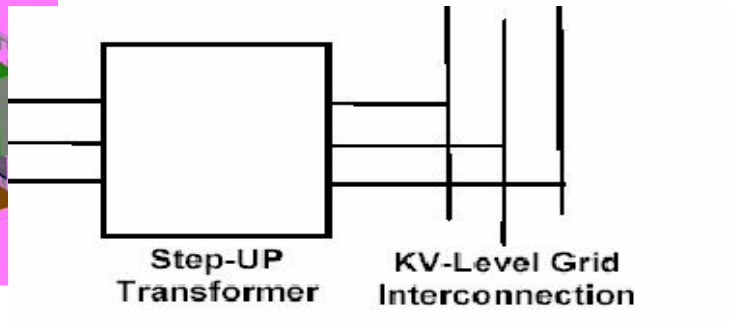
System Operation

Signal from ISO





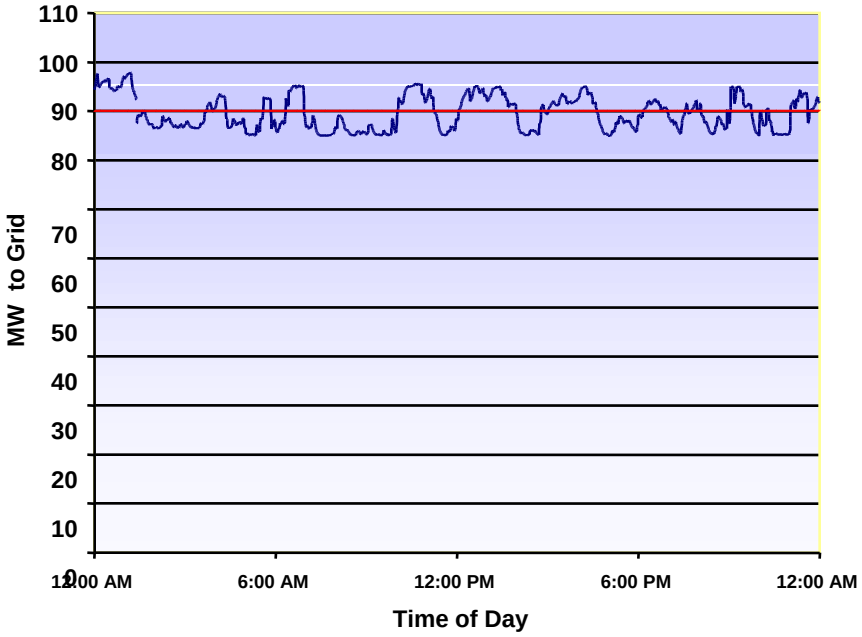
Injects or absorbs power to/from the grid in accordance with ISO signal



Smart Energy Matrix (SEM)

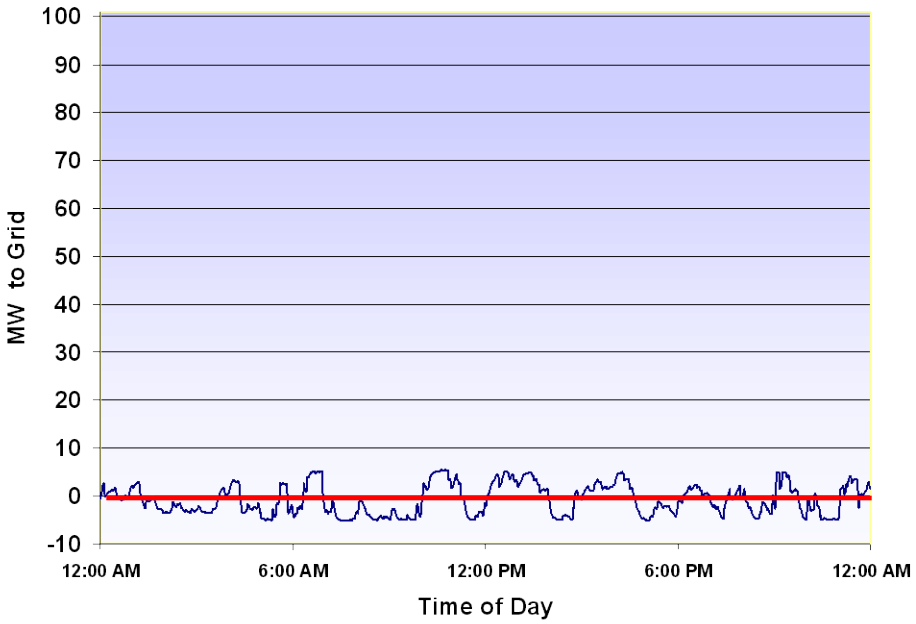
Regulation Using Generator vs. Energy Storage

100 MW Generator
Set at 90 MW with 5 MW Regulation



- Generator varies output
  - Decreases efficiency
  - Increases emissions

Energy Storage providing 5 MW of Regulation

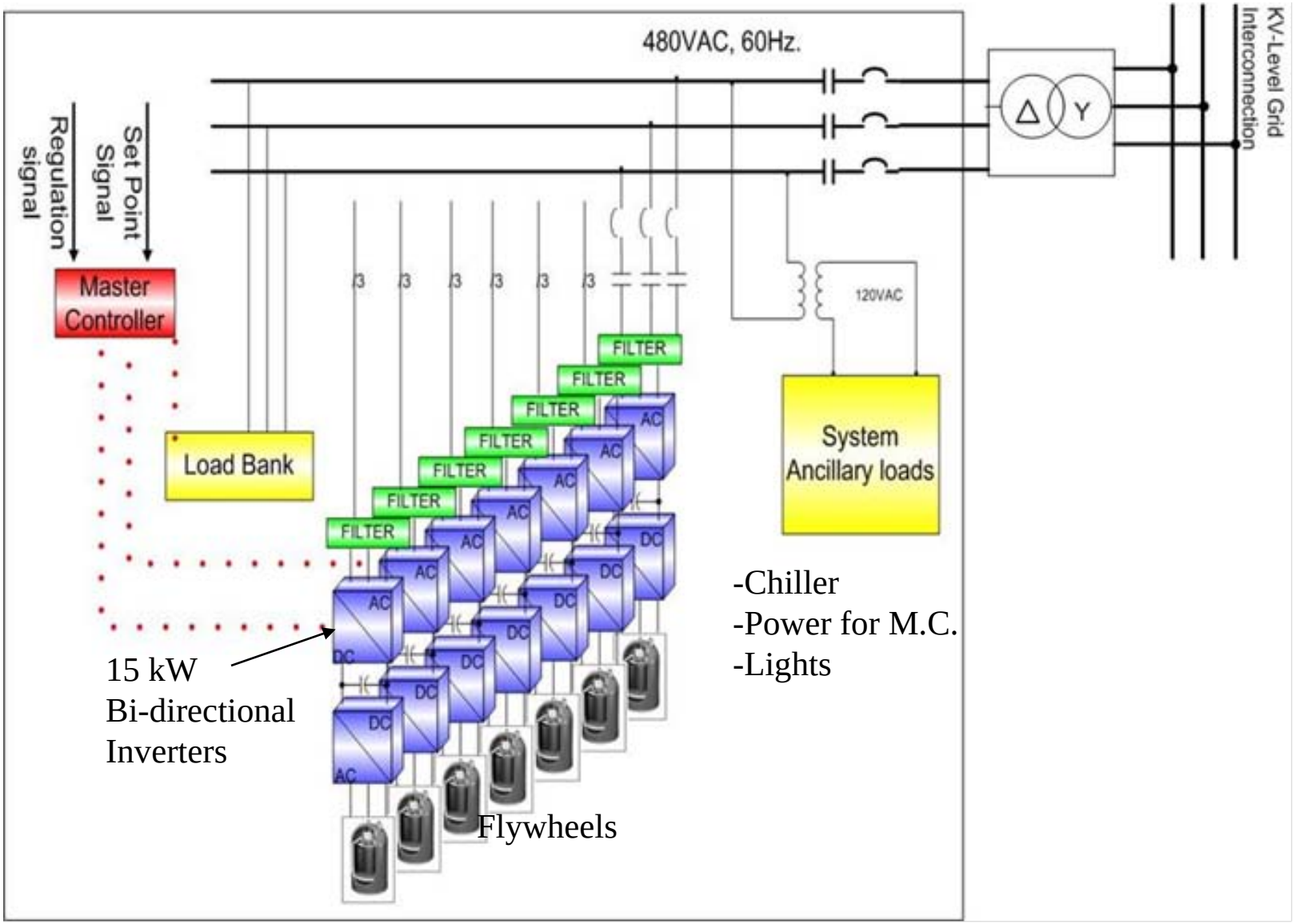


- Flywheel recycles energy
  - High round trip efficiency
  - Zero emissions

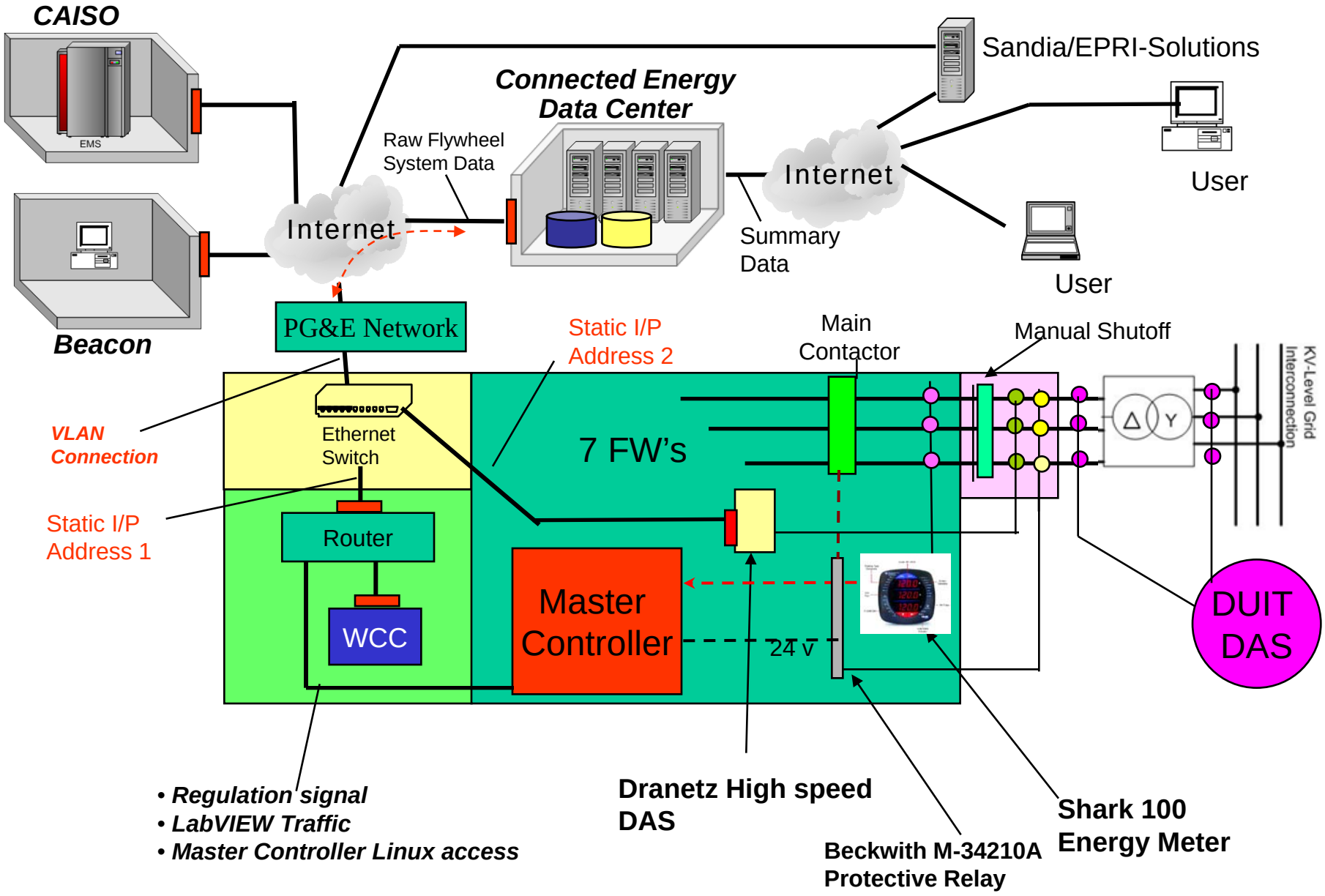
Outside View of System

Inside View of System

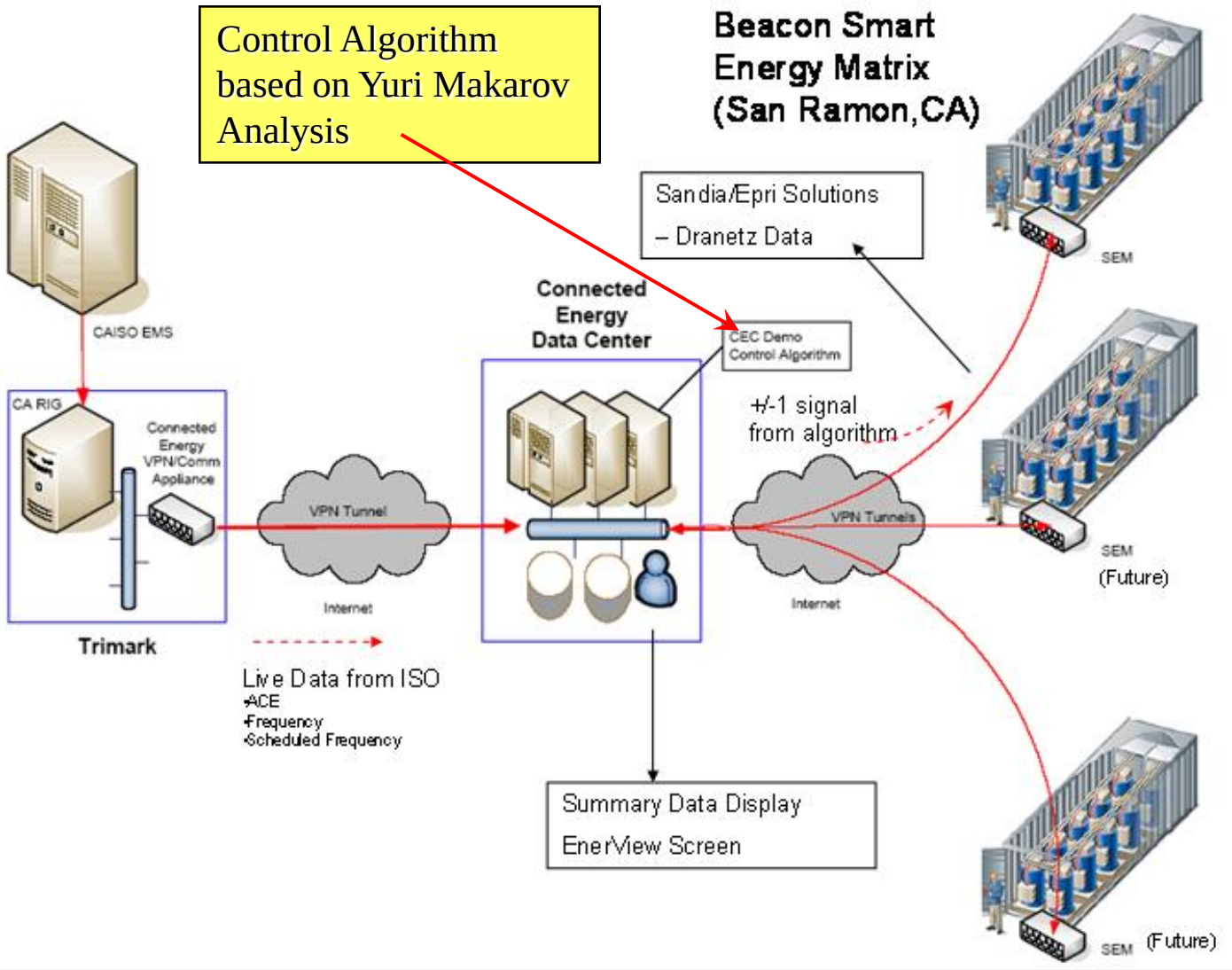
Demo Schematic



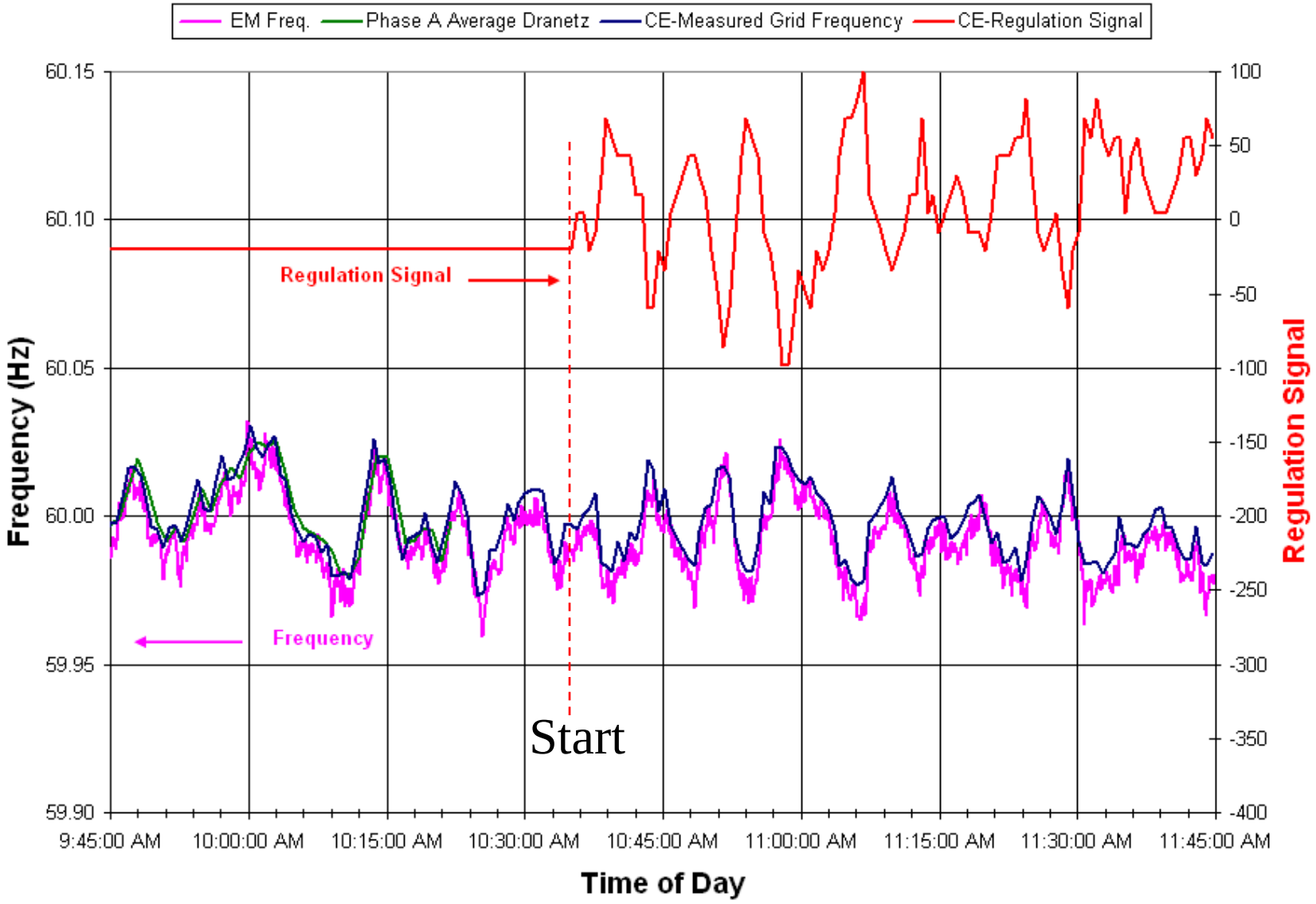
Data Communication Topology



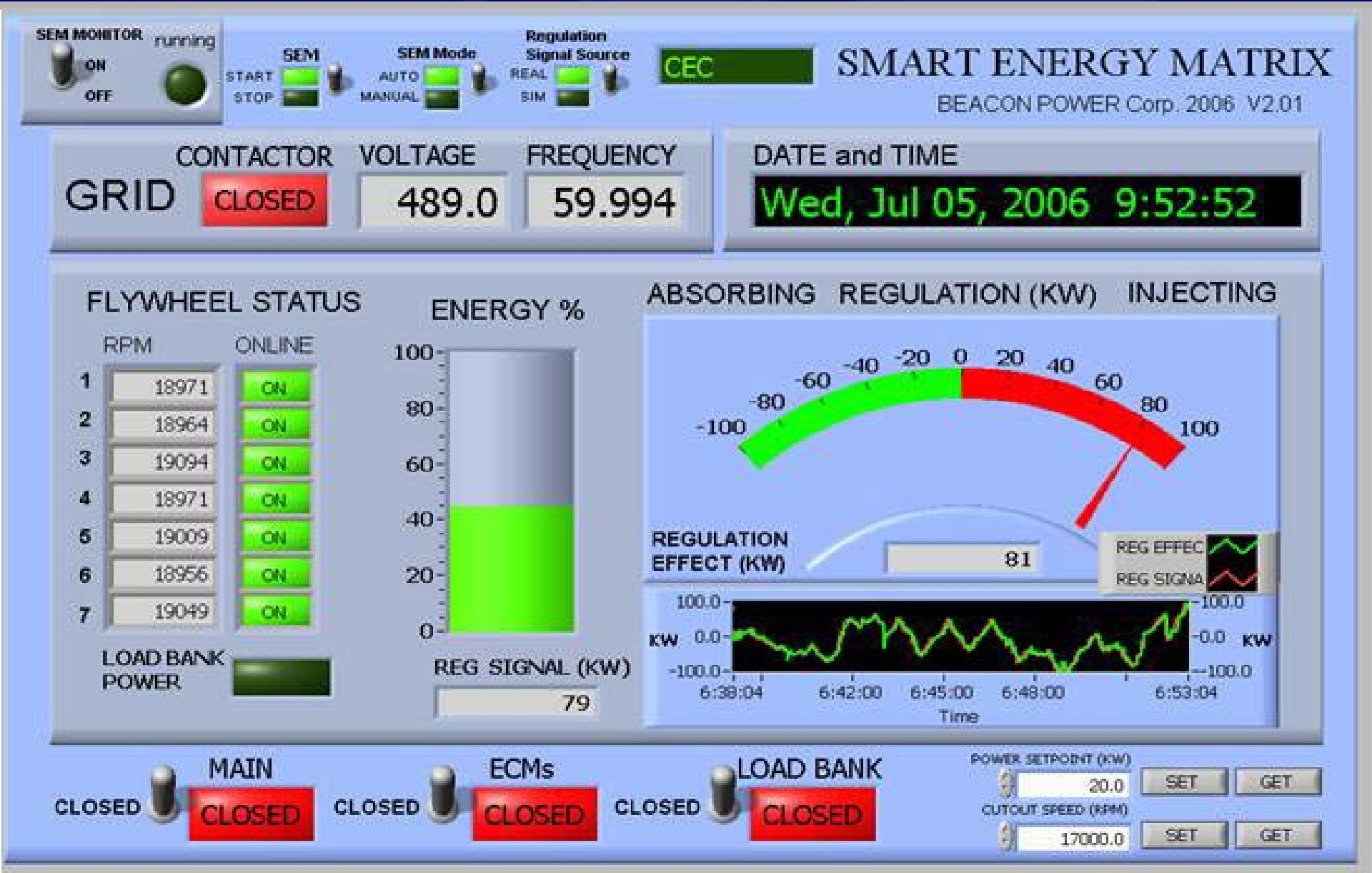
Control Signal Schematic (CEC)



Regulation Signal Generated from Frequency
(NYSERDA)



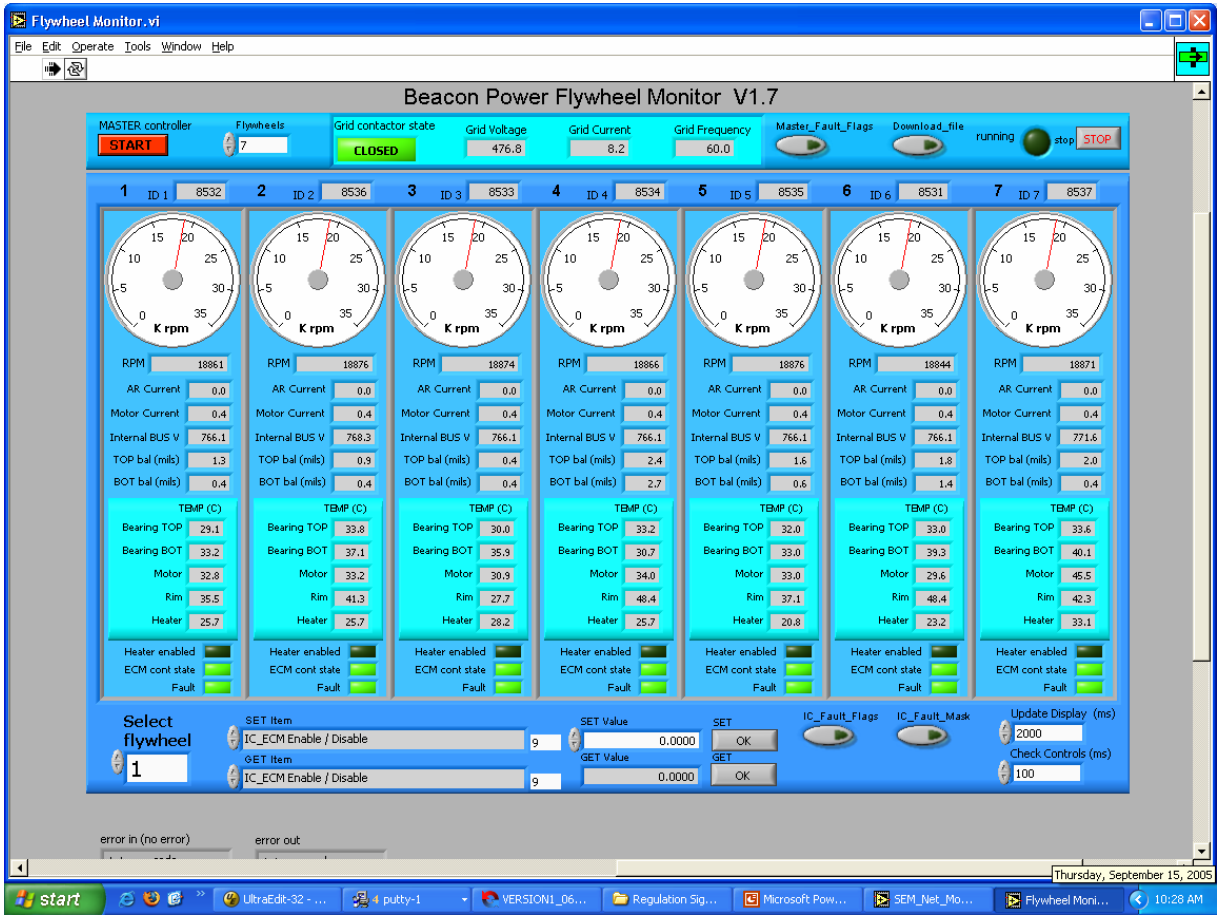
System Graphic User Interface



Flywheel Graphical User Interface

Beacon POWER

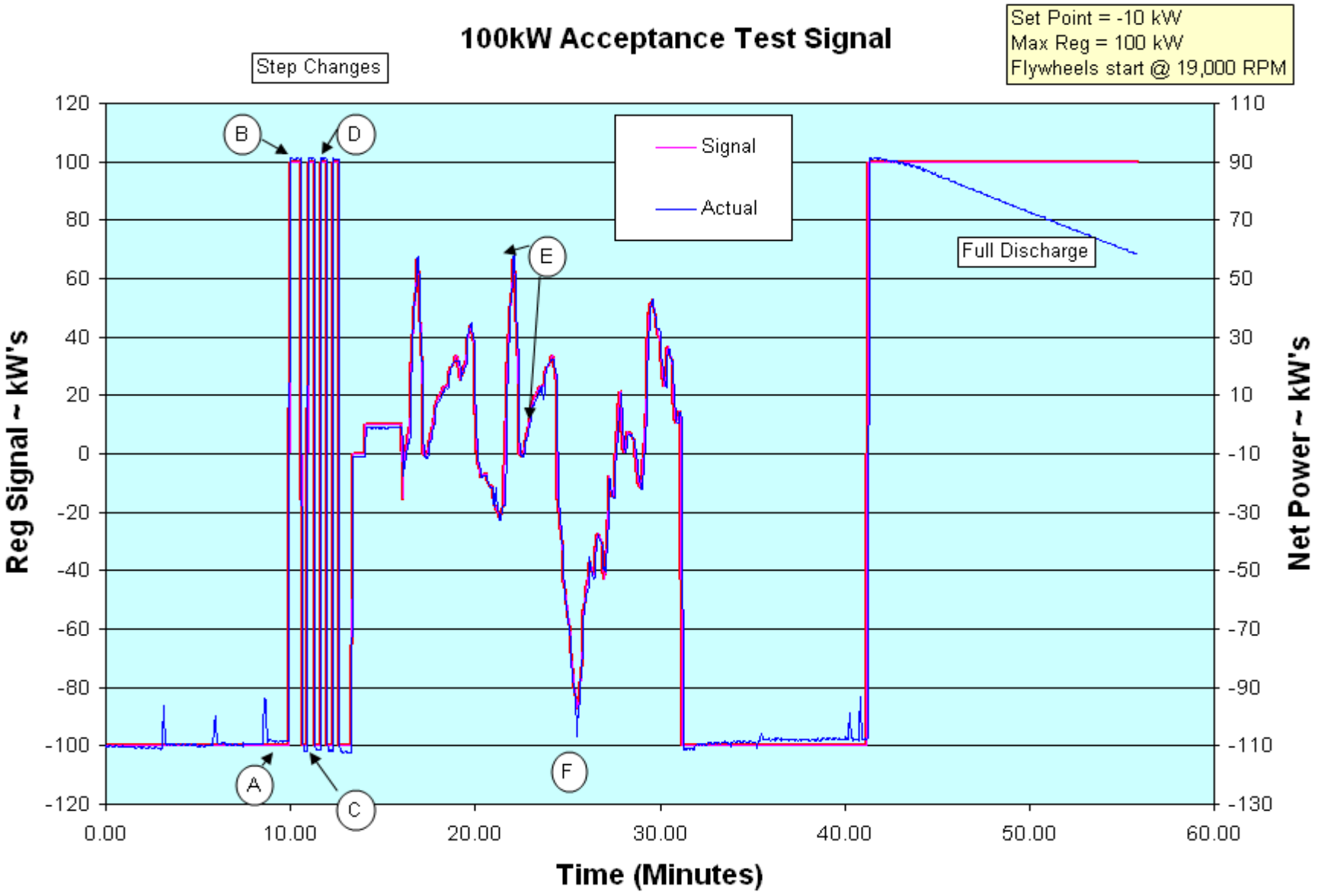
Remote Monitoring and Control of Flywheel and System Parameters



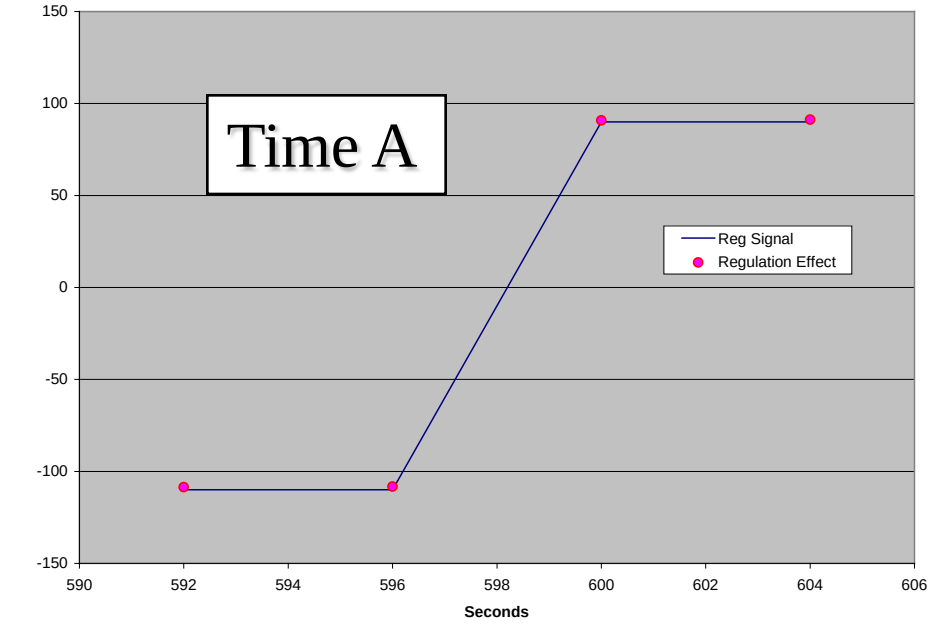
Test Results

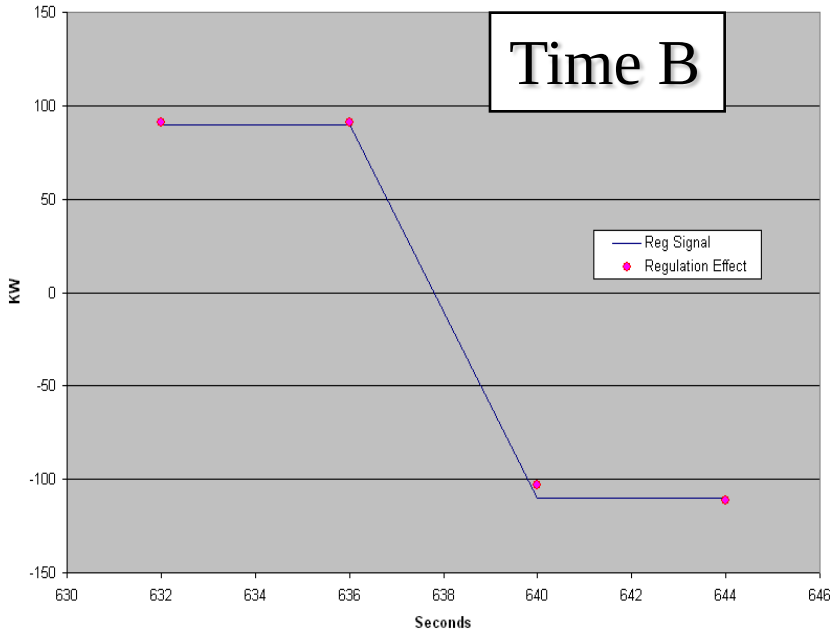
- Initial Acceptance Test
  - System Response Time
  - Slam Test
  - Typical Daily Response to Signals
  - Daily Performance Summary
  - Monthly Performance Summary
  - Reactive Power Response
  - Summary of Test Results
  - Status vs. Objectives

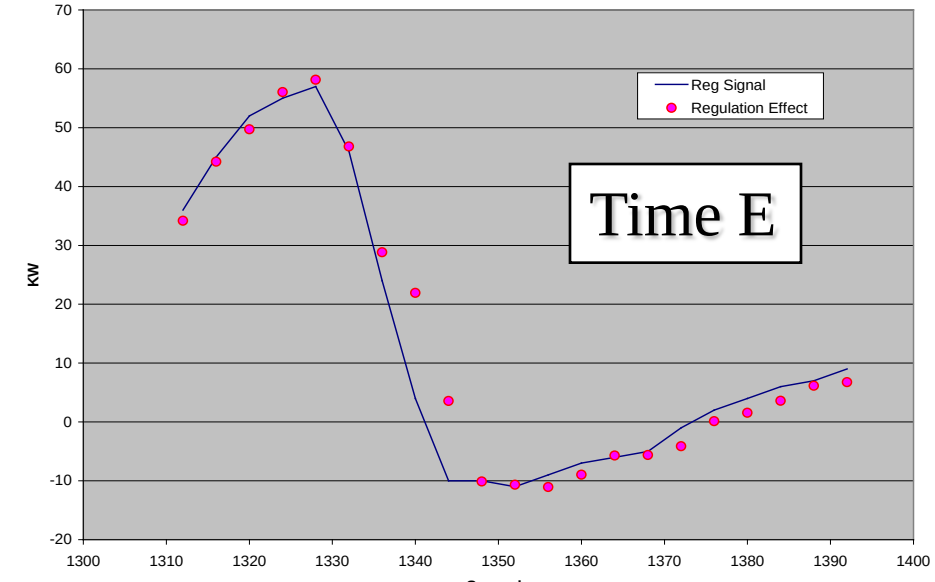
Acceptance Test Data

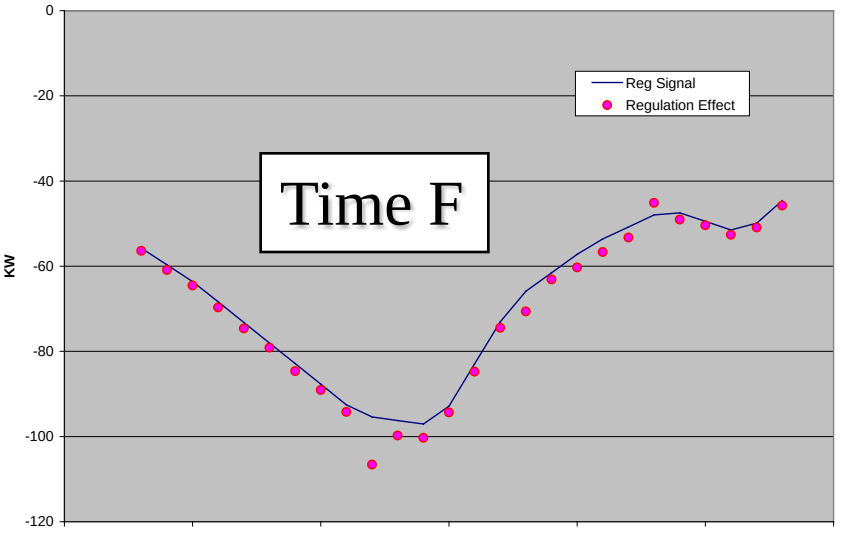


System Response Time

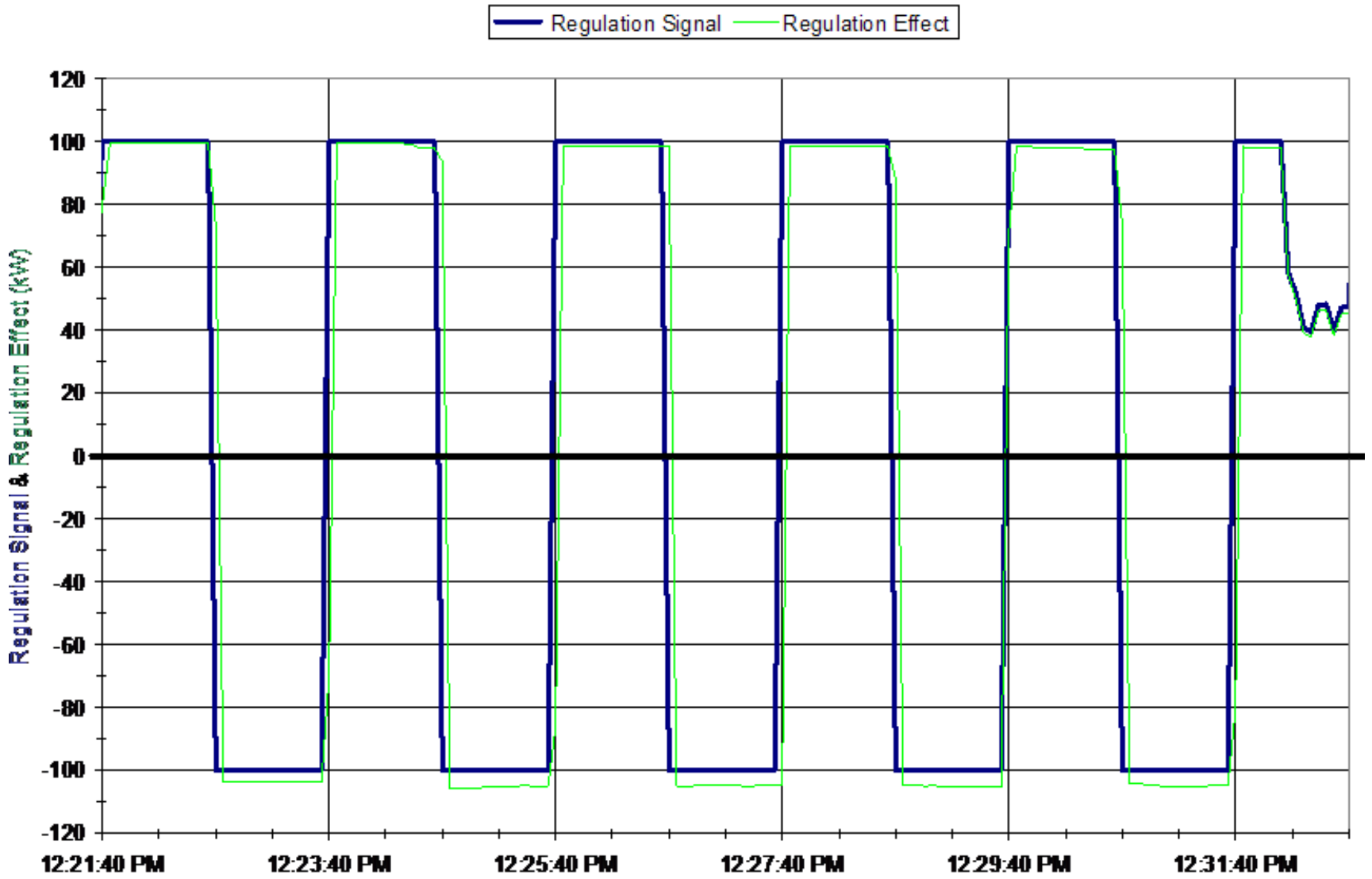






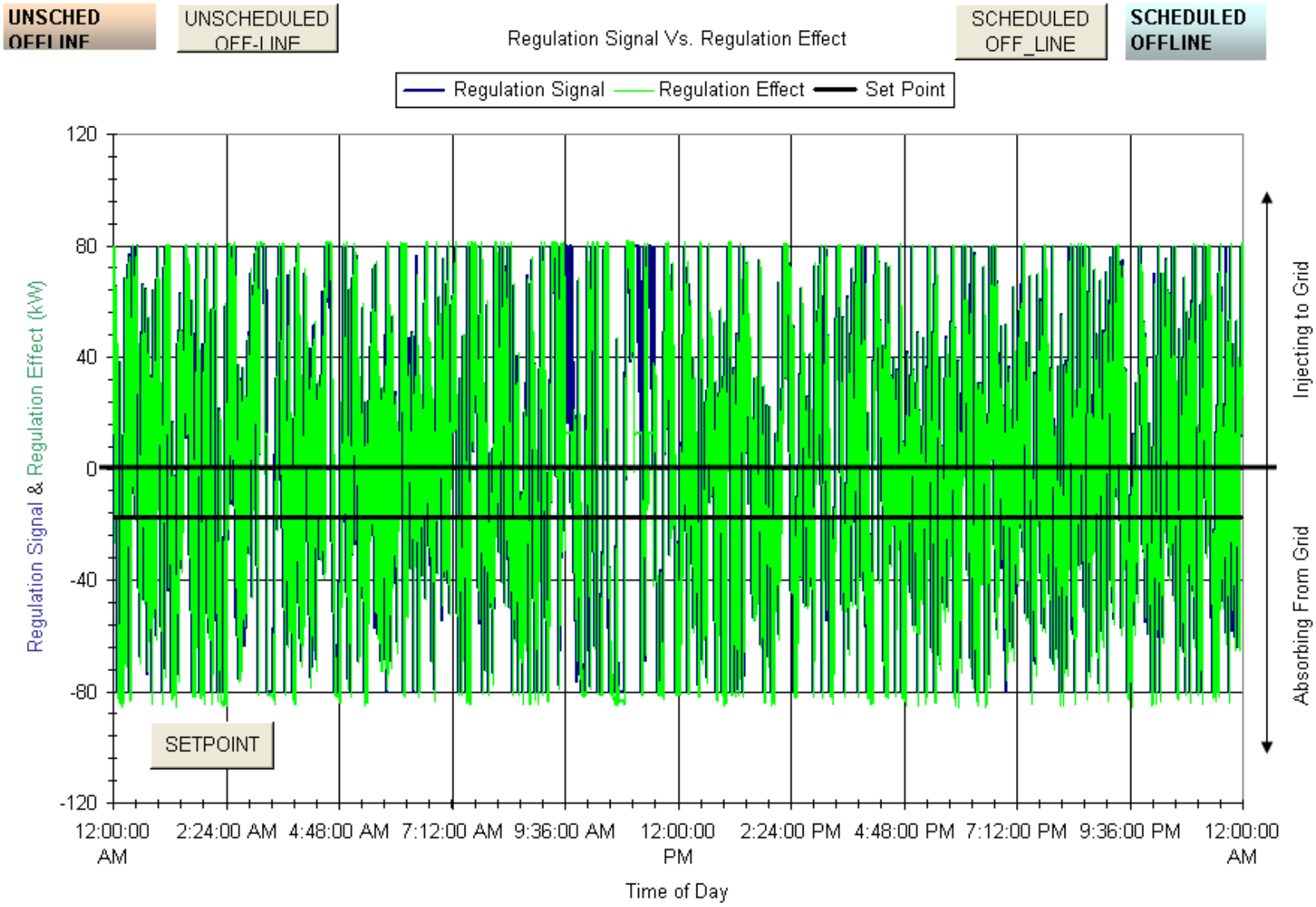


Results – Slam Test



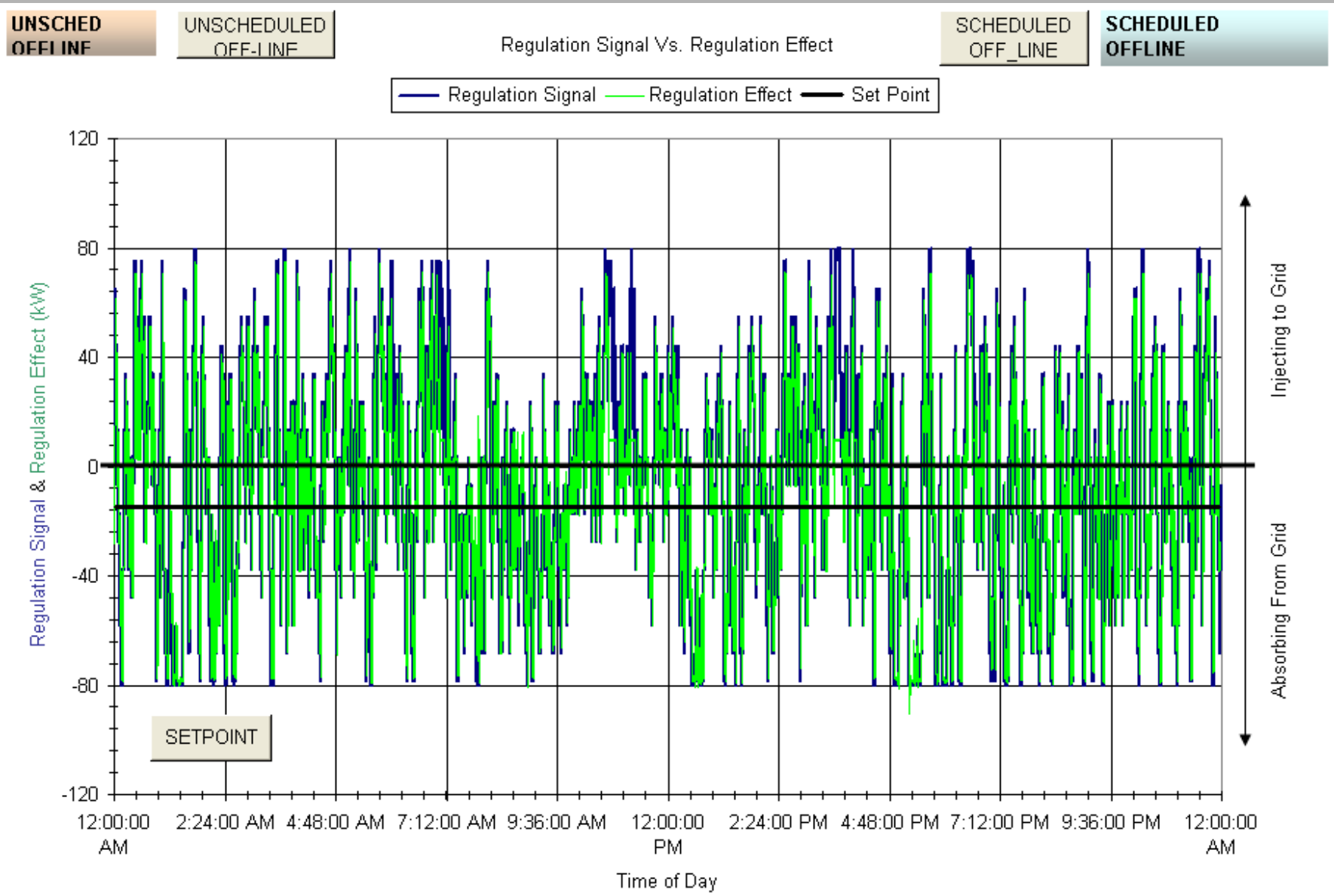
Typical CEC Response

(August 2, 2006)



Typical NYSERDA Response

Sept 28, 2006



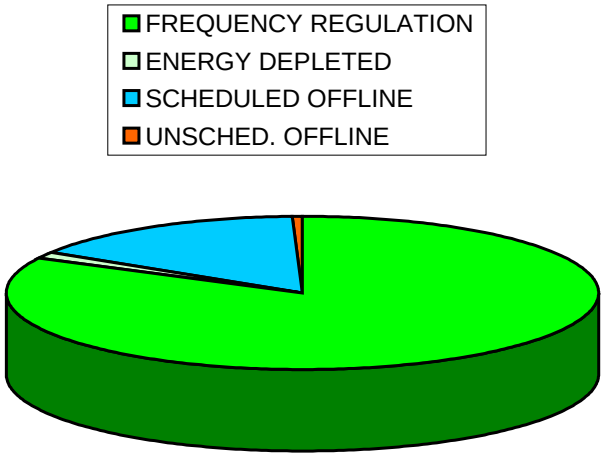
Monthly Performance Summary

(CEC - Aug 2006)

CEC Run Data Monthly Summary Sheet **Date: August, 2006**

Beacon Power Proprietary Information

		Percent	Hours
DAILY SUMMARY	**FREQUENCY REGULATION**	**86%**	**20.5**
	ENERGY DEPLETED	**1%**	**0.3**
	SCHEDULED OFFLINE	**12%**	**2.9**
	UNSCHED. OFFLINE	**1%**	**0.2**
	Total	**100%**	**24.0**
ON-LINE PERFORMANCE	**Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs**	**97.6%**	
	Deviation Excluding Depleted Time	**2.2%**	
	Deviation Including Deplete Time	**3.1%**	



Monthly Performance Details

(CEC - Sept 2006)

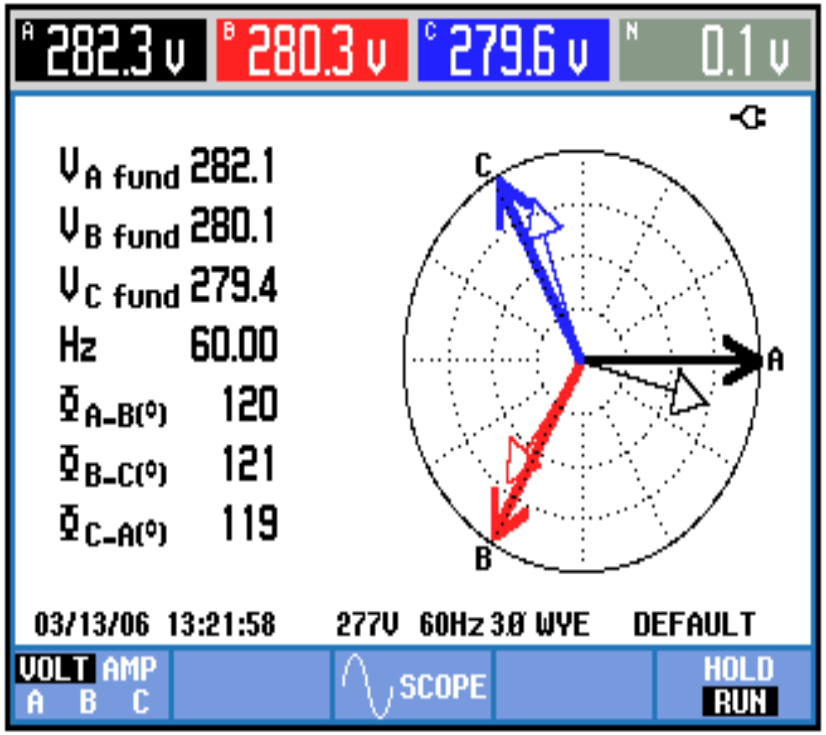
Beacon POWER

September, 2006 SEM Performance Summary												
Date	Freq Reg	Energy Depleted	Total Online	offline unsced	offline sched	Deviation	Deviation w/ depletion	Max KW	Setpoint KW	Cutout Speed RPM	Max FW's	Comments
6-Sep	22.57	0.30	22.86	0.00	1.14	2.41%	3.19%	60	17.5	17,000	7	Offline time being reviewed
7-Sep	23.64	0.30	23.94	0.06	0.00	2.32%	3.04%	60	17.5	17,000	7	
8-Sep	19.35	0.32	19.66	0.00	4.34	1.95%	2.87%	60	17.5	17,000	7	The regulation signal flatlined for several hours
9-Sep	0.00	0.00	0.00	0.00	24.00	2.57%	3.73%	0	17.5	17,000	7	The regulation signal flatlined al day
10-Sep	12.63	0.55	13.18	0.00	10.83	1.62%	4.23%	80	17.5	17,000	7	The regulation signal flatlined for several hours
11-Sep	22.42	0.21	22.63	0.61	0.76	1.74%	2.30%	80	17.5	17,000	7	
12-Sep	23.72	0.35	24.07	0.00	0.00	1.98%	2.91%	80	17.5	17,000	7	
13-Sep	23.43	0.58	24.01	0.00	0.00	2.20%	3.65%	80	17.5	17,000	7	
14-Sep	23.93	0.07	24.00	0.00	0.00	1.98%	2.91%	80	17.5	17,000	7	
15-Sep	23.37	0.64	24.01	0.00	0.00	1.95%	3.56%	80	17.5	17,000	7	
16-Sep	23.45	0.56	24.01	0.00	0.00	1.94%	3.34%	80	17.5	17,000	7	
17-Sep	23.43	0.58	24.01	0.00	0.00	2.12%	3.55%	80	17.5	17,000	7	
18-Sep	23.44	0.56	24.00	0.00	0.00	2.43%	3.88%	80	17.5	17,000	7	
19-Sep	13.91	0.76	14.67	0.00	9.33	1.99%	5.10%	80	17.5	17,000	6	
20-Sep	21.84	0.68	22.52	1.48	0.00	1.76%	3.59%	80	17.5	17,000	6	
21-Sep	22.76	0.61	23.37	0.63	0.00	3.01%	4.37%	60	17.5	17,000	6	
22-Sep	23.61	0.39	24.00	0.00	0.00	3.92%	4.85%	60	17.5	17,000	6	
23-Sep	23.63	0.38	24.00	0.00	0.00	3.86%	4.77%	60	17.5	17,000	6	
24-Sep	23.62	0.38	24.00	0.00	0.00	3.96%	4.86%	60	17.5	17,000	6	
25-Sep	23.61	0.40	24.00	0.00	0.00	3.95%	4.87%	60	17.5	17,000	6	
26-Sep	23.63	0.37	24.00	0.00	0.00	3.89%	4.81%	60	17.5	17,000	6	
27-Sep	23.62	0.38	24.00	0.00	0.00	3.83%	4.77%	60	17.5	17,000	6	
28-Sep	10.29	0.17	10.46	0.00	13.54	3.59%	4.47%	60	17.5	17,000	6	The regulation signal flatlined for several hours
29-Sep	0.00	0.00	0.00	0.00	24.00	2.57%	3.73%	9	17.5	17,000	6	The regulation signal flatlined al day
30-Sep	0.00	0.00	0.00	0.00	24.00	2.57%	3.73%	9	17.5	17,000	6	The regulation signal flatlined al day
Average for September	19.80	0.37	20.17	0.11	3.73	2.57%	3.73%					

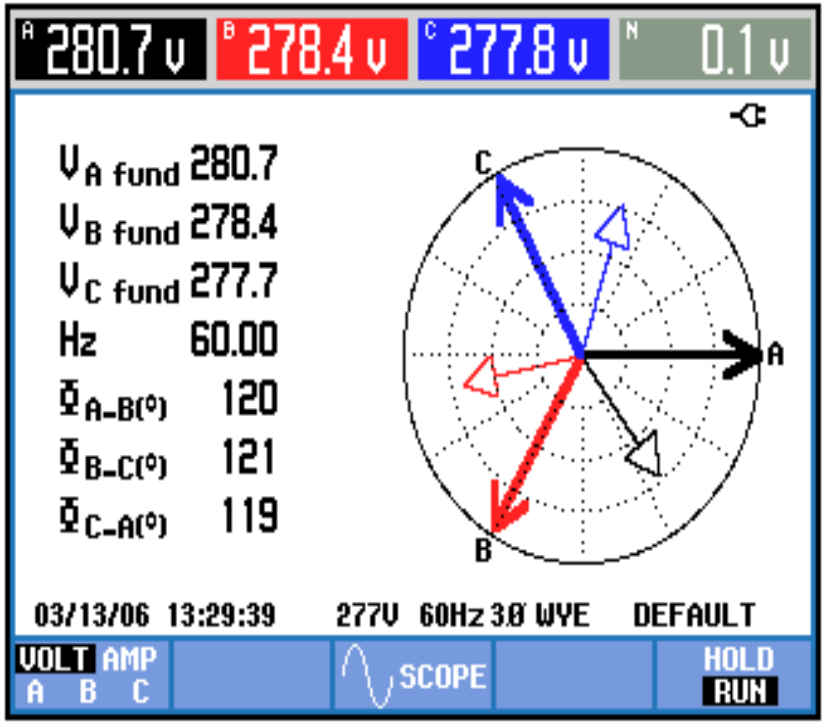
System online 20+ hours per day. Majority (>90%) of offline time is scheduled. Deviation from signal less than 4%.

Reactive Power Response (NYSERDA)

Phasor diagram at 50KW with and without reactive power (inductive)



50KW



50KW charge, 50KVAR, PF= 0.472

Test Results Summary

- CEC system has been operating for over a year with only two scheduled system shutdowns. NYSERDA since February also with two shutdowns.
- Testing successfully characterizing flywheel response to fast-acting regulation signals
- System reliability being validated
  - Startup / quality issues encountered and addressed as they occur
  - Flywheel reliability has been excellent with two minor issues addressed on site
  - Lessons from demo systems being used to improve design and reliability of the full-power system under development for 2007
- No technical barriers to product introduction have been identified
- Final phase should focus on establishing a signal that can be used for full-power product introduction and identify associated economic value

Performance testing nearing completion. No technical barriers identified. Lessons being incorporated in product design.

Status vs. Objectives

Objective	Status
Proof of concept on ~1/10th power scale	100kW demonstrated vs. 1 MW (or greater) product
Show ability to follow fast-changing frequency regulation signals	Response time of 4 seconds demonstrated (see data)
Demonstrate anti-islanding	Complete - using standard Beckwith relay
Validate interconnection capability	Connected to grid with no adverse impact
Demonstrate performance and economic value	System performance demonstrated. Economic value analysis being worked with ISOs.
Develop and demonstrate communications with grid operators	All communications systems working
Collect data for product specifications	Data being collected and summarized. Lessons from demo being reflected in the full-power system under development.
Report results - gain industry confidence	Site demonstrations to key stakeholders. Data being distributed.

Programs on schedule to meet all objectives

Beacon Flywheel Product Evolution

2000

Gen 1
Telecom
2 kWh / 1 kW

2001

Gen 2
Telecom
6 kWh / 2 kW

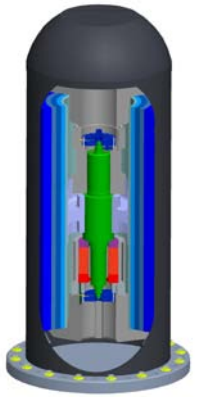
2004

Gen 3
Grid
6 kWh / 15 kW

2005

100kW
demonstration unit

2006



Gen 4
Grid
25 kWh / 100 kW

2007

1st MW operational in
commercial service

- Telecom applications
- Over 500,000 hours of operation

Gen 4 - 25kWh/100kW Flywheel Hardware

Rim

Housing

Gen 4 - 25kWh/100kW Flywheel

Related Applications

- Other potential applications being considered for flywheel technology
  - Mitigation of grid angular instability
  - Reactive power injection / absorption
  - Renewable ramp mitigation
  - UPS
  - Peak power
  - Micro-grid power regulation
  - Renewable energy integration