Grid Frequency Regulation by Recycling Electrical Energy in Flywheels

Final Report 08-06
July 2008

New York State
Energy Research and
Development Authority

NYSERDA

NYSERDA

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Grid Frequency Regulation by Recycling Electrical Energy in Flywheels

Final Report

Prepared for the

New York State Energy Research and Development Authority

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NOTICE

ABSTRACT

Beacon Power has developed (and applied for patent coverage for) an innovative means to provide frequency regulation with the use of flywheel energy storage rather than by cycling the output of a generator. The intent of the regulation service is to add and subtract power (as directed by the Regional Transmission Operator), but to have a net zero output. The concept proposed would recycle energy (store energy when generation exceeds loads; discharge energy when load exceeds generation) instead of trying to constantly adjust generator output. This cyclic characteristic of regulation services makes a flywheel energy storage system uniquely suited to the application. The method the company proposes was developed in close cooperation with several ISOs (Independent system operators) including the NYISO. It can perform as many cycles as required, with no impact on its performance. In theory other energy storage such as batteries, could provide this service, but are not practical because of the reduction of capability and life, resulting from repeated cycles.

Prior to launching a full scale production system Beacon was awarded a contract to demonstrate the concept using a scaled system. A prototype scaled system was built and tested at Beacon's facility in Wilmington, MA and then installed at Power & Composite Technologies, Inc (PCT) manufacturing facility in Amsterdam, NY. After a series of development tests, an eight month performance test was completed to evaluate the system ability to follow various regulation signals and demonstrate reliability. In addition, a test demonstrating the ability of the system to provide reactive power to the grid was also performed. Results are presented that indicate the system can follow a rapidly changing signal and go from full power in one direction to full power in the other in less than four seconds. All program objectives were met, including significant technology transfer and commercialization plans. The original plan was to operate the system for eighteen months continuously, however after eight months it was agreed that sufficient data was collected to show the systems performance. (See amendment to the test plan in Appendix 8.3). Results were evaluated by the NYISO and they confirmed the flywheel technology to be acceptable and viable for use in the New York ISO grid. They are currently working to determine how the service would be integrated into their tariff structure. (See quote from NYISO in Appendix 8.4.)

Data was also collected and analyzed by EnerNex (subcontracted by the Department of Energy). This data is being reported to Sandia National Laboratories (SNL) under Contract DE-AC04-94AL85000. (See appendix 8.9 for validation of the data)

Keywords: flywheels, regulation, ancillary service, energy storage

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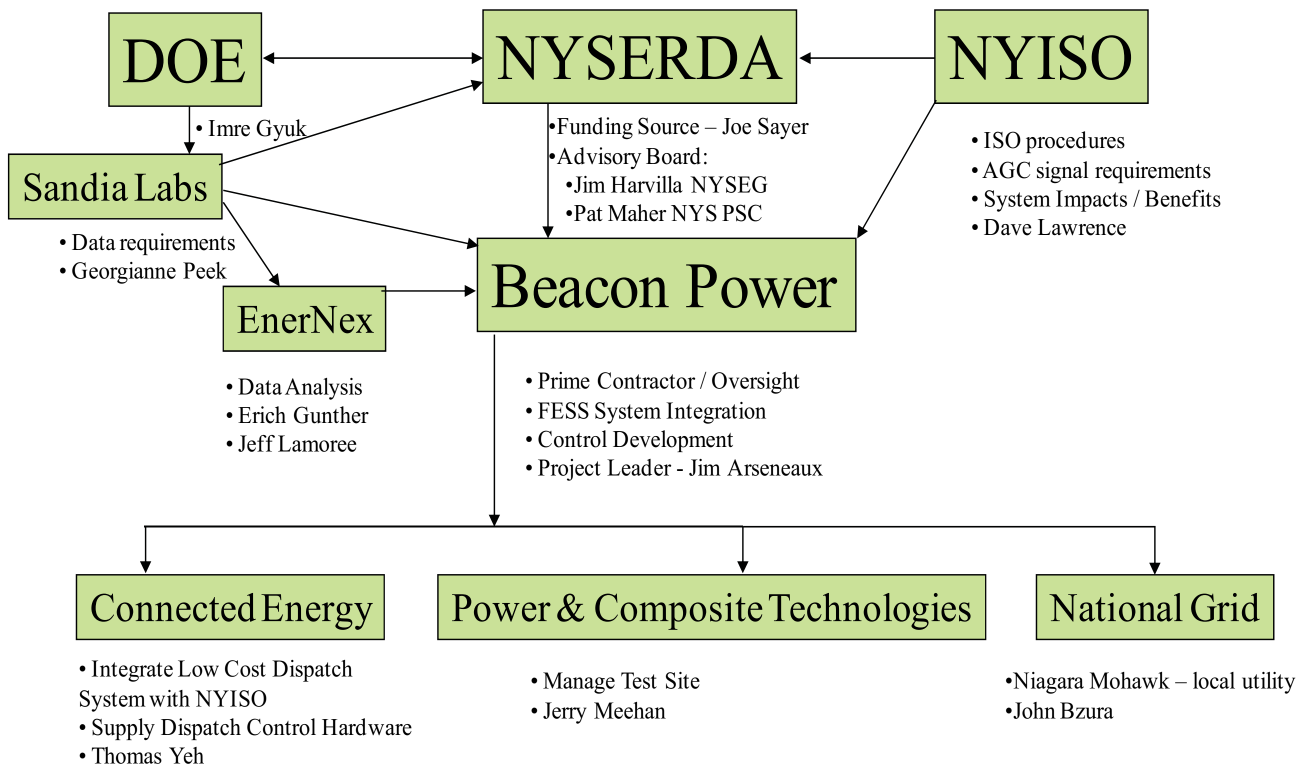
Project Team



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Executive Summary

Introduction

Beacon Power has developed (and applied for patent coverage for) an innovative means to provide frequency regulation with the use of flywheel energy storage rather than by cycling the output of a generator. The method that the company proposes was developed in close cooperation with several ISOs including the NYISO. This demonstration project was awarded and executed to show how this concept would work on a scaled system.

Project Approach

Key stakeholders from DOE, NYSERDA, NYISO, NYSEG, Sandia National Labs, Connected Energy, National Grid, EnerNex, and Beacon Power were organized to address all aspects of the project from planning, design, commissioning, testing, and reporting the results. The project was broken into the following 14 tasks.

1. Project Administration
2. Project Plan
3. FESS Design
4. Controller Design
5. Site Preparation and Interconnection
6. Component Procurement
7. System Assembly and Test at Beacon
8. Data Acquisition Design and Integration
9. FESS Installation at PCT
10. Training
11. Test Planning
12. Preliminary Test
13. Long- term Testing
14. Technology Transfer

Project Objectives

- Proof of concept on ~1/10th power scale
- Show ability to follow fast-changing frequency regulation signals
- Demonstrate anti-islanding
- Validate interconnection capability at the end of a distribution system
- Demonstrate performance and economic value
- Demonstrate Reactive Power capability
- Collect data for product specifications
- Gain industry confidence
- Report results to the industry

Project Outcomes

The system was designed, commissioned, and a field trial test was completed. The system demonstrated availability to respond to a fast changing frequency regulation signal and provide regulation 97.2% of the time it was online. Reliability of the system was demonstrated and changes needed to meet product reliability requirements were identified. A commercialization plan was completed, including conceptual design of a 20 MW Flywheel Frequency Regulation Plant. An analysis of emissions savings for a 20 MW flywheel plant compared to other sources of regulation shows significant savings over the operating life of a plant. Life Cycle Cost of performing regulation with a flywheel system was estimated and compared to other sources of regulation. Results showed a lower cost than any other type of regulation. The system demonstrated ability to provide both capacitive and inductive reactive power when requested.

Conclusions

The demonstration project accomplished all of its original objectives. The data, lessons, and stakeholder interactions have demonstrated that using fast acting energy storage is a viable method to perform grid regulation. The benefits have been quantified and data has been shared and validated by all stakeholders. The demonstration project was a key step in moving the concept of Frequency Regulation using Flywheel Energy Storage from a concept to detail design of a commercial 20 MW facility.

Recommendations

In order to obtain the maximum benefit of fast acting regulation services using Flywheel Energy Storage in NY, additional integration is required with the NYISO. Initial discussions with the ISO are centered on building a 20MW flywheel facility to perform regulation services as a direct replacement for current generators. In order to fully utilize the benefits of fast acting regulation, a non-generator regulation service should be established. This would establish market rules to take advantage of the fast response, while eliminating the rules that are currently written to be compatible with existing generators that provide energy and regulation under the existing rules. NYISO is working on a Demand Response program, however this is for all ancillary services and is not specific to fast responding regulation providers. A separate service that covers fast- acting, regulation-only services, could provide benefits to the ISO, its customers, and eliminate unnecessary constraints to the providers.

Benefits to NY as a result of this project

The demonstration project validated the benefits cited in the original proposal with additional quantification. If a 20 MW Flywheel facility were installed in NY it would provide the following benefits:

- Increase the supply of competing regulation service providers
- Significant reduction in Emissions of CO_2, SO_2, and NO_x
- 20 MW of additional generation capacity would be available from generators
- If a separate service was defined for fast acting regulation, a reduction in the ACE (area control error) would be possible. This would result in a more stable grid and likely reduce the amount of total regulation service required. This could lead to reduced overall operating cost.

1.0 Introduction

1.1. Background

Today's transmission and distribution grid has been described as the greatest technological achievement of the century. Perhaps the most challenging aspect of the grid is the fact that the amount of power generated and the amount of power consumed must be in exact balance at all times. When imbalances occur, the frequency that the users of electricity expect (60 Hz or 50Hz depending on the continent) will not be maintained. When generation exceeds consumption, the frequency increases, and when generation is less than the aggregate load, the frequency decreases. An analogy to this occurs when a lawn mower encounters high grass; the engine's constant power supply is presented with a suddenly increased load, and the speed (frequency) is reduced. This constant balancing of load and generation to maintain frequency is called Frequency Regulation. Figure 1 below illustrates the difference between Frequency Regulation and daily load changes.

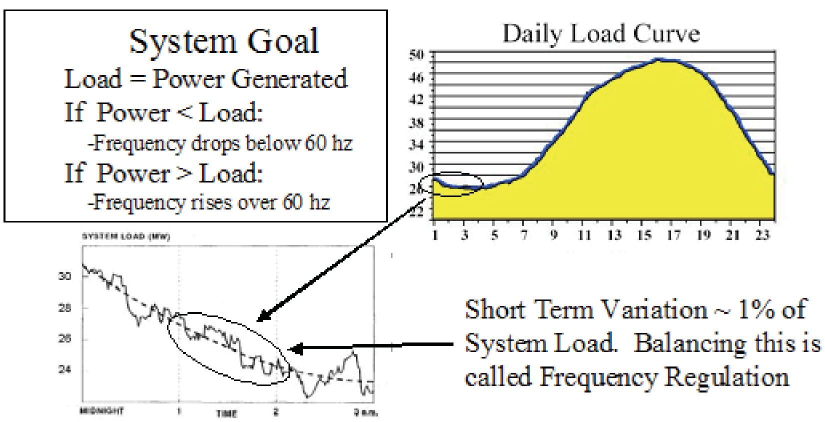


Figure 1 - Frequency regulation versus daily load changes

Generators that supply power to the grid have a substantial combined inertia. The impact of this inertia is that a large amount of surplus power will only slightly increase their speed. The generators within a specific control area are also all synchronized to the same frequency. This combination of facts provides an effective buffer against the inevitable imbalances that occur when loads are quickly added or subtracted, or generators drop off line. Imbalances that occur more slowly increase or decrease the frequency of the grid and must be corrected for by making constant adjustments to generators to keep the frequency within required limits. This constant cycling increases the wear on the generators and requires them to be run off design and at a lower efficiency. The cost impact of this reduced efficiency, lower generation, and increased maintenance has a direct impact on the profitability of the generators.

In a vertically integrated utility, frequency regulation is managed by the utility and the cost is buried with other operating cost. In a deregulated electric system the activity of balancing loads and supply (Frequency Regulation) has become a separate service and it can be provided by a number of participants. Based on frequency and other system measurements, the Control Area Operator sends a signal to the Regulation Service Providers, who increase or decrease their generator output to restore equilibrium. Generator owners bid into the open market to provide this service and are compensated separately from their power generation. In order to remain profitable they must be compensated for their lost generation revenues and cost to their equipment. Otherwise they would bid only into the energy markets to maximize their profits.

The evolution of the deregulated electric system has created an opportunity for new participants to compete in open markets to provide the service of frequency regulation to system operators. It also has created a unique opportunity to use a new technology to provide this service that has historically had limited solutions.

1.2. Program Overview

Beacon Power has developed (and applied for patent coverage for) an innovative means to provide frequency regulation with the use of flywheel energy storage rather than by cycling the output of a generator. The method that the company proposes was developed in close cooperation with PJM (Pennsylvania/Jersey/Maryland Regional Transmission Operator), CAISO (California Independent System Operator), ISO-NE (Independent System Operator-New England) as well as the NYISO (New York Independent System Operator). Each ISO has reviewed the concept, and has encouraged Beacon Power to pursue the use of flywheel energy storage to provide frequency regulation services to their respective ISOs.

The intent of the regulation service is to add and subtract power (as directed by the Regional Transmission Operator) but to have a net zero output. In other words, if an electrical meter were attached to the output of the regulation service, it would spin in one direction and then the other, but would end up about where it started. The concept proposed would recycle energy (store energy when generation exceeds loads; discharge energy when load exceeds generation) instead of trying to constantly adjust generator output. This cyclic characteristic of regulation services makes a flywheel energy storage system uniquely suited to the application. It can perform as many cycles as required, with no impact on its performance. In theory, other energy storage, such as batteries, could provide this service, but are not practical because of the reduction of capability and life, resulting from repeated cycles.

Analysis of the existing frequency regulation signals indicates that an energy storage module, which can store or deliver 1MW for 15 minutes, would provide regulation services superior to services provided by current generators. Scaling up Beacon Power's current flywheel from six to 25 kWh of stored energy and packaging 10 flywheels in a matrix, would provide this capability with low technical risk. We refer to this combination of ten 25kWh flywheels in a matrix as a Smart Energy Matrix (SEM). During the process of this project, discussions with the stakeholders have indicated that multiple MW facilities would be easier to interconnect. The general consensus is that a 20MW facility would be a good initial size. This would allow for a reduced interconnection process, be large enough to have an impact, but not too large to impact the competitiveness of the market. Based on this, the DOE awarded Beacon Power a contract to design such a facility.

Losses in the SEM will be less than 15% and can be managed by setting a nominal offset in the regulation provided. The offset will be a small constant power consumption, which can be accounted for by the system operator without affecting the performance of the regulation system. The SEM will follow the regulation signal within a fraction of a percent for more than 90% of the day. This compares to some existing generators, which have difficulty following the fast changing signal and are often a large % off the current signal, depending on the type of generator.

Unlike generation based frequency regulation, no fuel is consumed, and no emissions are generated. This will allow for a greatly simplified and accelerated process for siting and permitting the equipment compared to conventional generators. The equipment can also be sited nearly anywhere, including at the substation or within the distribution system. If sited in the distribution system, additional benefits such as voltage regulation, backup power, or reactive power can be offered to enhance the value of the product.

2.0 Project Approach

2.1. Stakeholders

Prior to initiating the contract, all stakeholders were identified and key roles defined. This was a jointly funded program with the NYSERDA and DOE providing funding. Beacon Power was the prime contractor and there was one subcontractor to Beacon. Connected Energy was responsible to integrate a low cost dispatch and control system and to provide secure connection across the Internet. This connection was also used to transmit test data to a data center in Rochester, NY. Figure 2 shows the reporting relationship of the key stakeholders for this project. In addition to this project the CEC (California Energy Commission) in conjunction with DOE issued a contract to install a similar Flywheel system in California. This project used a similar hardware, but was tested at a PG&E test site near a substation to get a sample of different interconnection effects. One of its focuses was to demonstrate communication between the system and the ISO. The system did not have ability to inject reactive power as in the NY system. Some results from that related project are included in this report, as they present a more complete picture of the system's capabilities.

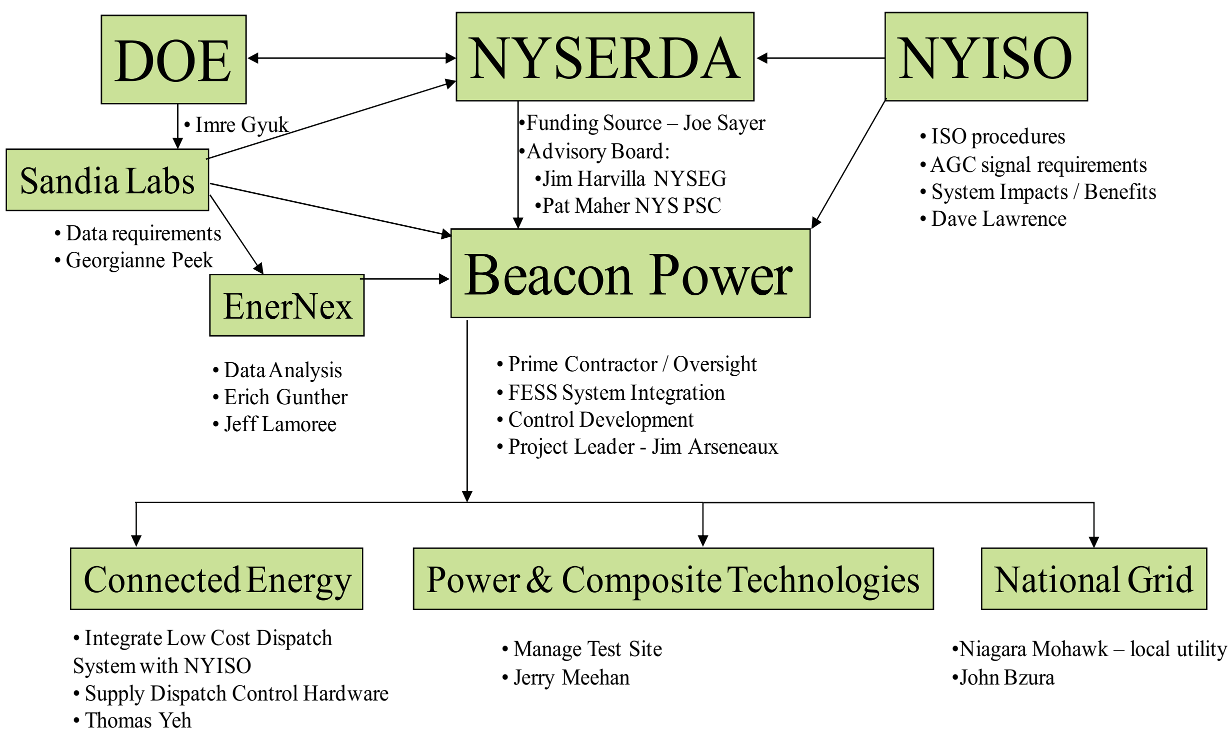


Figure 2 – NYSERDA Project Team

2.2. SOW Task

The project was defined by 14 specific tasks as shown below. Task 1 and 2 encompassed the project administrative and reporting task. Task 3 –14 were the technical task. All tasks were completed per the original plan and reviewed during Critical Program Reviews.

1. Project Adminstration
2. Project Plan
3. FESS Design
4. Controller Design
5. Site Preparation and Interconnection
6. Component Procurement
7. System Assembly and Test at Beacon
8. Data Acquisition Design and Integration
9. FESS Installation at PCT
10. Training
11. Test Planning
12. Preliminary Test
13. Long-Term Testing*
14. Technology Transfer

*Long-Term testing was reduced from 18 months to eight months per agreement with NYSERDA and DOE. It was agreed that sufficient data had been collected for the performance analysis. Additional durability testing was of limited value as this was demonstration hardware and the production system would be a larger flywheel with different hardware. See amendment to the test plan in Appendix 8.3.

2.3. System Description

The demonstration system was constructed with seven modified Beacon BHE6 flywheels. The flywheels were installed in a modified 20 Ft. X 8 Ft. shipping container. The container incorporated the ancillary equipment that included the cooling system, exhaust fans, master controller, and power conversion modules. This hardware is shown in figure 3.

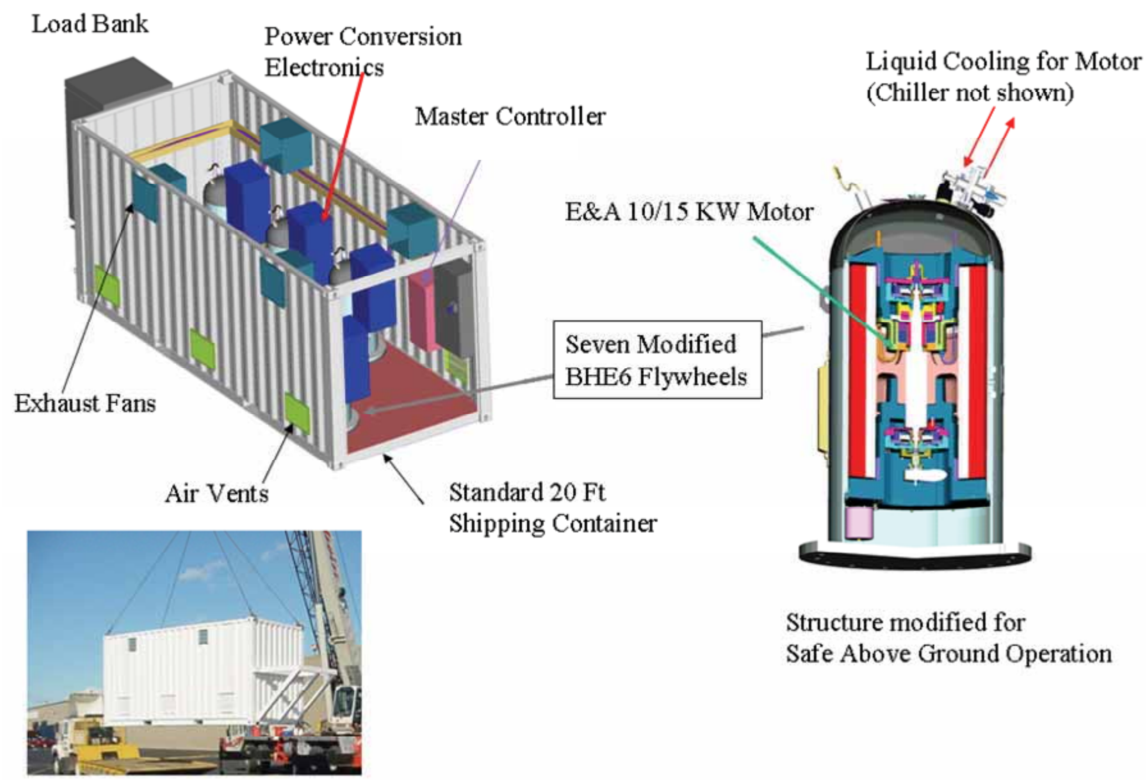


Figure 3 - Hardware for Frequency Regulation Project

Figure 4 shows the external view of the complete system installed at the test site at PCT in Amsterdam, NY. The only connections required at the test site were the 480 Vac three phase connections and a single internet connection. The system was unloaded from a flatbed truck with a crane. Once unloaded, the installation took only a few hours and the system was ready to power up.

Figure 5 is an inside view of the system showing the flywheels, cooling pipes, electronic modules, and the master controller.

Figure 4 - The completed system installed in the PCT Facility

Figure 5 - Inside view of the Demonstration System

A complete set of assembly drawings and Bill of Material was supplied to the NYSERDA program manager as a deliverable for Task 3 of this project.

2.4. System Operation

In the basic mode of operation the Smart Energy Matrix is a device that stores energy when requested and returns it, when directed to by the ISO, by an automatic signal as shown below.

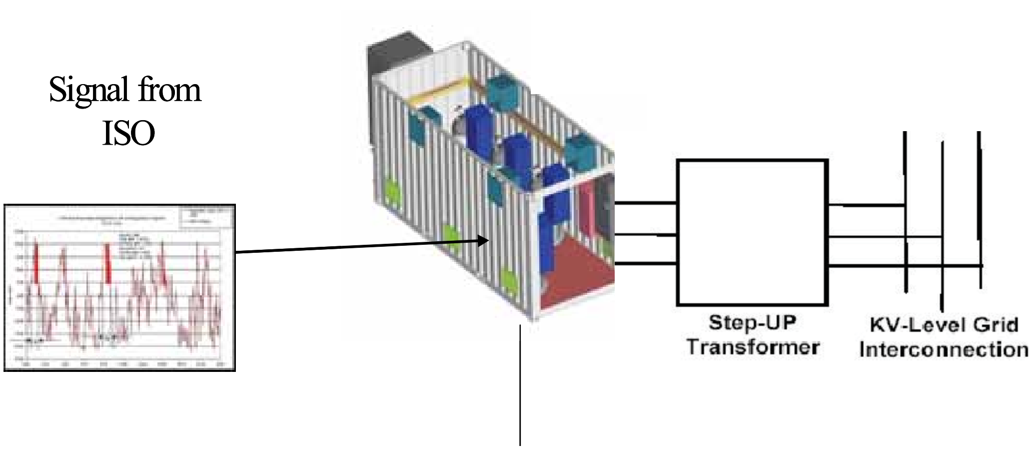


Figure 6 - SEM System Operation

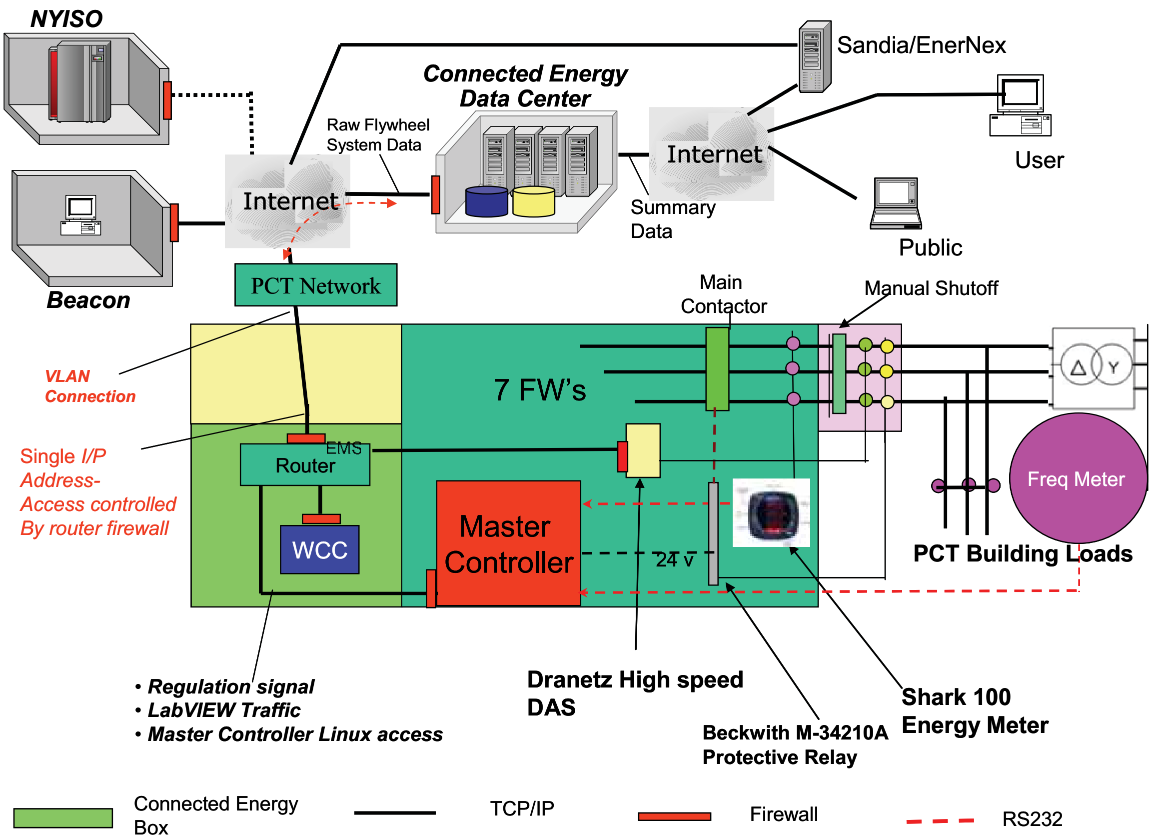


Figure 7 - Data Communication Topology

Figure 7 shows additional details, including how data is collected and communicated over a secure internet connection to the Connected Energy data center in Rochester, NY. Data is also collected by a high speed Dranetz DAS. This data was reviewed by EnerNex and reported under a separate contract.

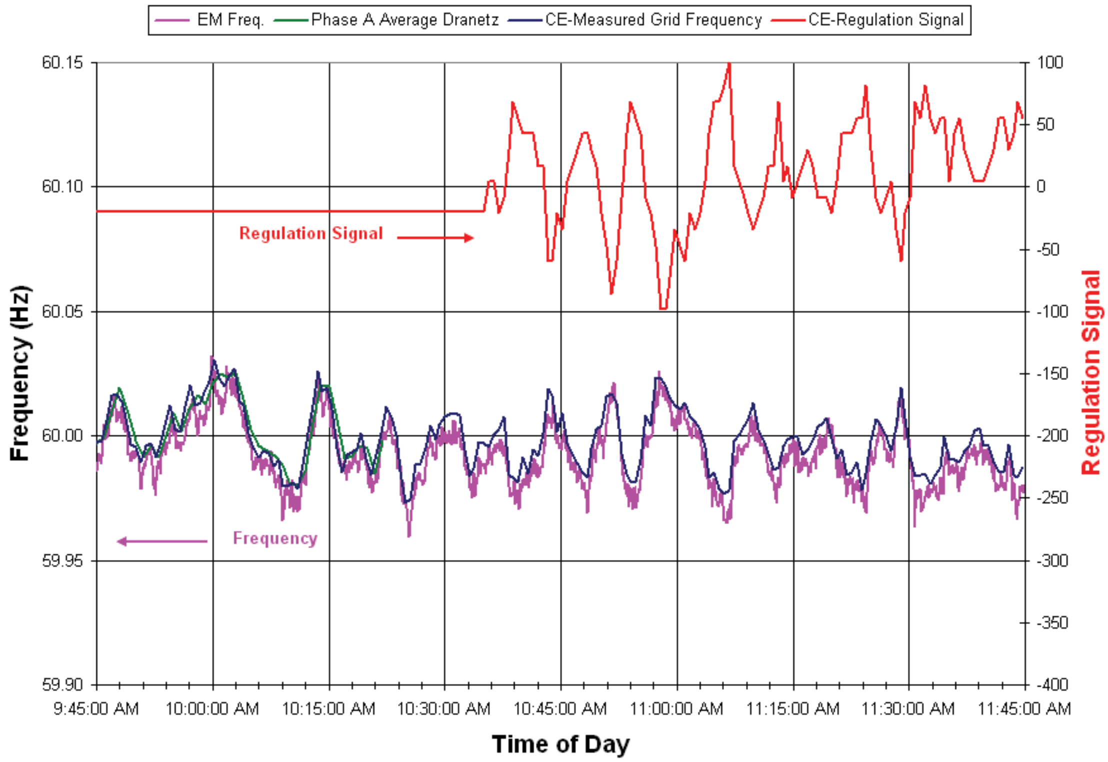


Figure 8 – Frequency Signal Generation

Figure 8 shows a plot of how measured frequency was converted via an agreed-to algorithm and used to dispatch the demo flywheel system. In a commercial product a regulation signal would be sent from the NYISO to the service provider to inject or absorb power. During the demo project, the ISO suggested we respond directly to frequency. As shown in the above plot, when the frequency was above 60 hz. (after the test start at ~10:37 AM), the system would get a negative signal indicating to absorb power from the grid. At times when the frequency was below 60 hz., the system would get a positive signal indicating to inject power to the grid. The data presented later in the report evaluates how the system responded to this signal.

Figure 9 shows the System Level GUI (Graphical User Interface) that is used to start the system and monitor system level operation.

Figure 10 shows the Flywheel Level GUI. This was used by engineers to monitor detailed operation of individual flywheels.

Once started, the system was automated, so no on-site personnel were required to run the system, which remained online 24 hours a day during the field trial period. If any parameter was out of preset limits, a fault was logged by the data system. Within several minutes this would trigger a text message to Beacon personnel who could review the fault remotely. They could then address the fault by reviewing the data and resetting limits, if appropriate, or shut an individual flywheel down and continue testing with the remaining flywheels. On-site test personnel could address any hardware issues the following day.

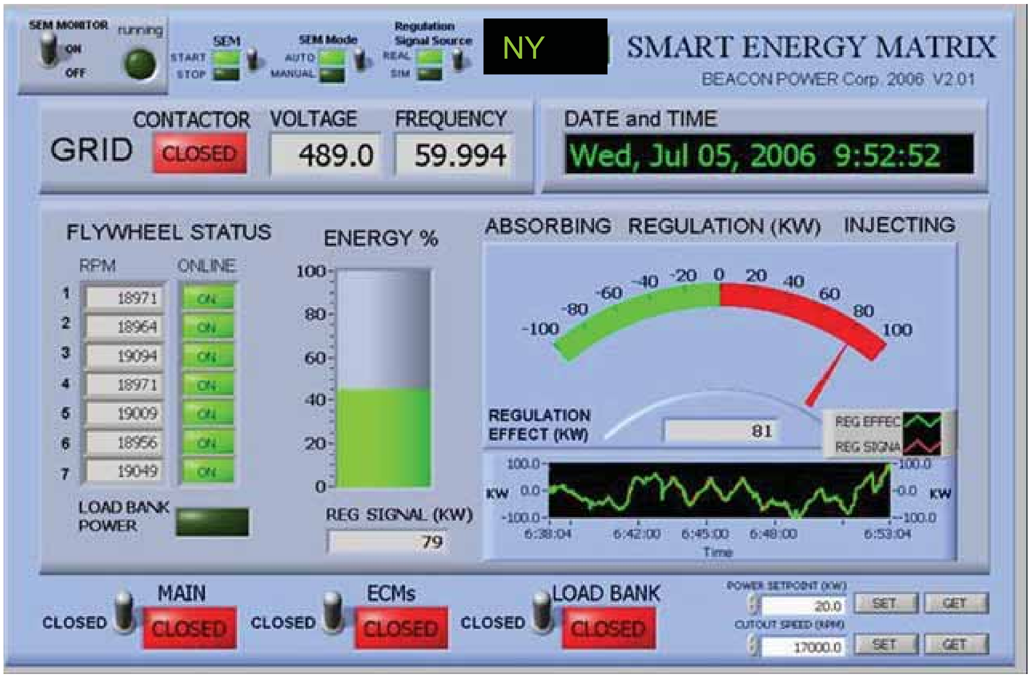


Figure 9 - System Level Graphical User Interface

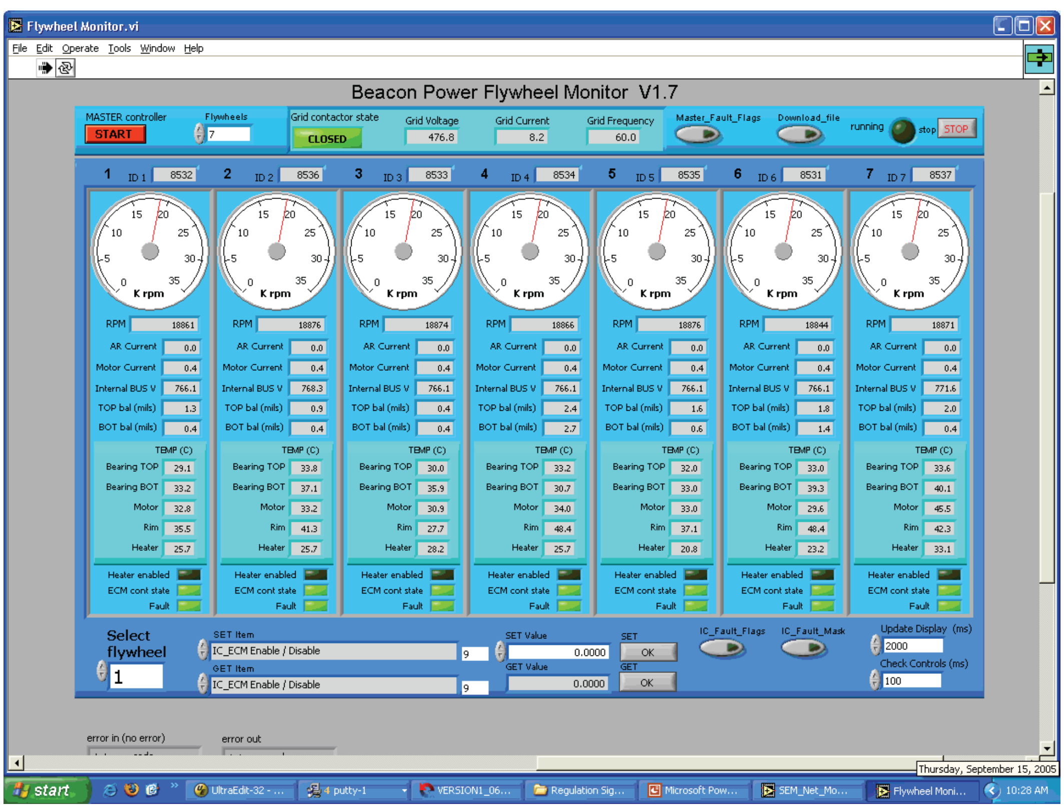


Figure 10 - Flywheel Graphical User Interface

2.5. Test Plan

The key functionality requirements include validating:

- Safety
- Communications and Controls
- Calibration
- Performance Envelope
- Dynamic Response
- Reliability

The field trial test plan was developed to demonstrate the ability of the SEM to follow a fast or slow changing regulation signal. In order to simplify the NY project these signals were generated on-site, based on frequency data. In commercial service the signal would be transmitted from the ISO. Data from the energy meter was collected every four seconds and stored on the system's master control computer. It was also downloaded to a data center managed by Connected Energy. Data was also collected on the Dranetz high speed data system and analyzed by EnerNex for the United States DOE. It correlated with the data that Beacon collected and analyzed. Overall performance and reliability was monitored and evaluated. Details of the test plan are included in Appendix 8.2. Field trial test results are discussed in Section 4 of this report and additional details are in Appendix 8.8.

3.0 Objectives

The following objectives were established during the kickoff meeting and monitored during critical project reviews. The status vs. the objectives is discussed in section 4.4

- Proof of concept on ~1/10th power scale
- Show ability to follow fast-changing frequency regulation signals
- Demonstrate anti-islanding
- Validate interconnection capability
- Demonstrate performance and economic value
- Develop and demonstrate communications with grid operators
- Collect data for product specifications
- Gain industry confidence
- Report results to the industry

4.0 Project Outcomes

4.1. Data Results and Analysis

Figure 11 shows a plot of how the system responded to a control signal during an acceptance test. It shows the test signal in kWs vs. time and the systems response (actual) vs. time. The various sections were chosen to show how the system responded to various fast changing regulation signals that were being considered.

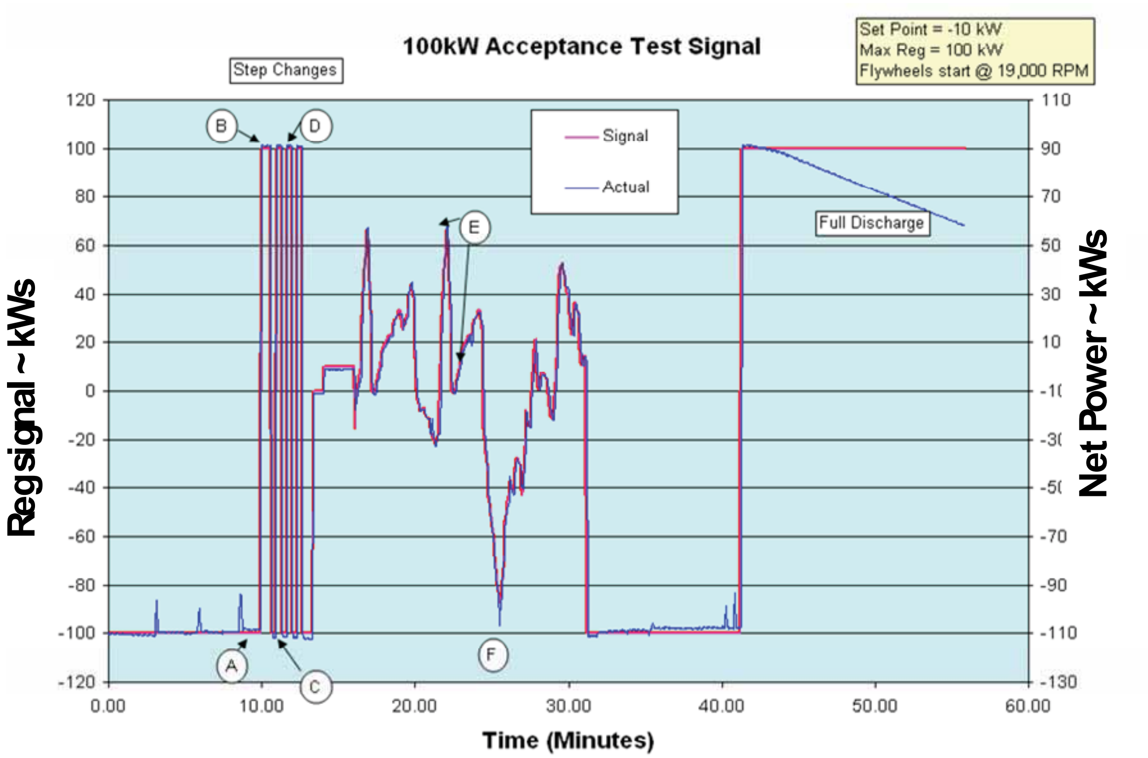


Figure 11 - System 100 kW Acceptance Test

The plots in Figure 12 show the response time of the system for several key times during the acceptance test. Note that both the signal and the response are updated each four seconds.

Time A- Response to change from 110 kW charge to 90 kW discharge with no measurable lag

Time B- Response to change from 90 kW discharge to 110 kW charge with no measurable lag

Time E - Explode view of the system responding to a typical charge signal (ACE smoothing) with four- second update

Time F - Explode view of the system responding to a typical discharge signal (ACE smoothing) with four second update

It should be noted that the four- second response time was limited by ramp rates in the electronics software as this was as fast as the current signal is updated for this project. The technology could be programmed to respond faster if required for other applications.

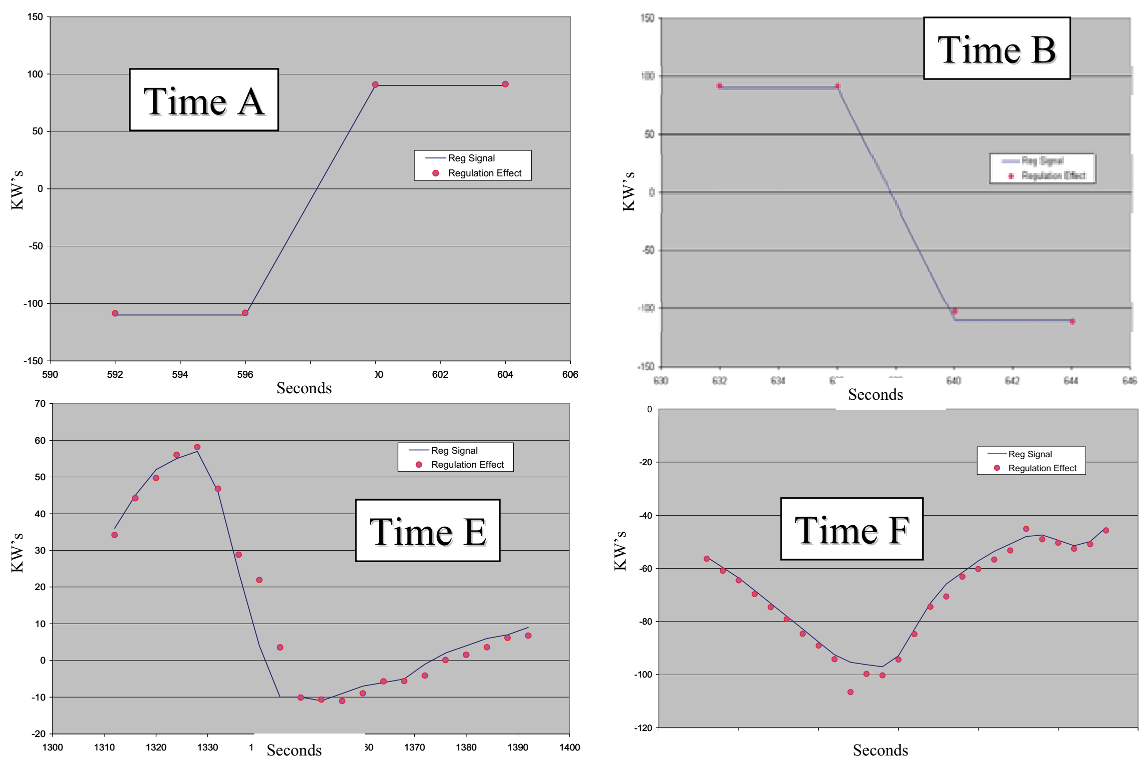


Figure 12 - Response time for four sections of the acceptance test

System performance data was collected 24 hours a day from July 1, 2006 to the end of February 2007. During this time, settings were varied to optimize system performance. Figure 13 is a typical plot of the system response to a signal generated from the frequency meter. As can be seen, the system responded to the fast changing signal and tracked well for most of the time period. During virtually all the time the system was asked to absorb energy (negative signal), it performed well. It also performed well when asked to inject energy for periods less than 15-30 minutes. When asked to inject power for extended periods, it ran out of energy as indicated by the blue sections of the plot. Based on this result and discussions with the ISO, DOE, and NYSERDA, it was agreed to modify the algorithm, which generates the signal, to be more representative of a 15 minute regulation service. This new approach is referred to as the frequency smoothing algorithm.

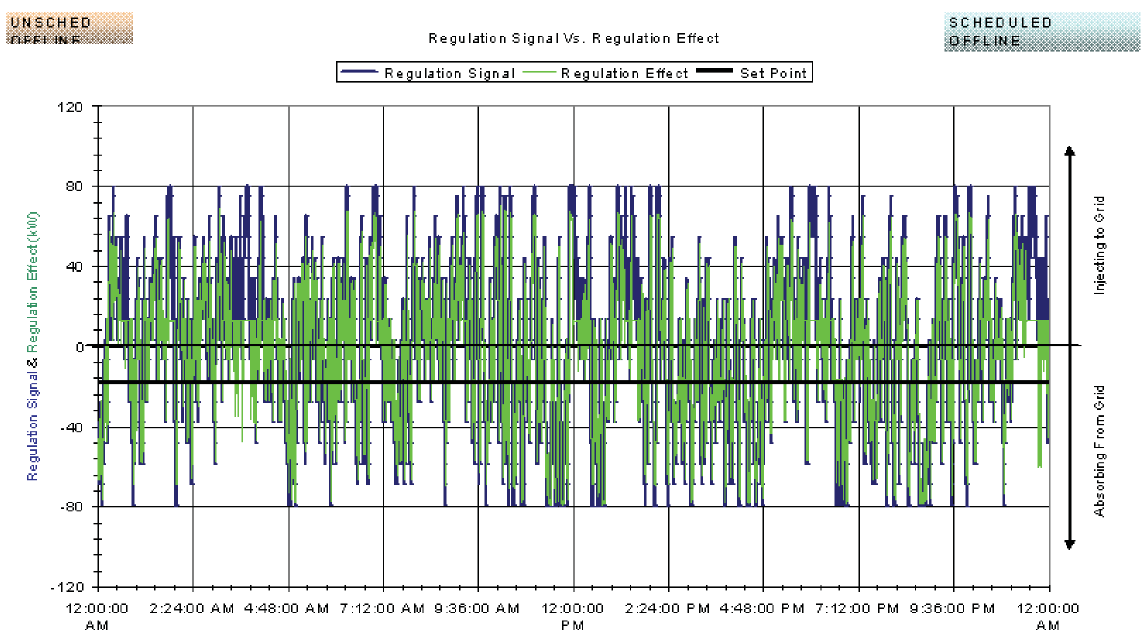


Figure 13 - Typical response generated from frequency signal

The frequency smoothing algorithm calculates the 10- minute rolling average of the real time frequency, and based on the instantaneous deviation of the frequency vs. the rolling average, it determines if the system needs to have power injected or absorbed and provides a signal to the flywheel system. The benefit of this signal is that it uses the fast acting flywheel system to respond to short duration imbalances and allows the remaining resources (mostly generators) to respond to the longer duration / slow changing imbalance.

Figure 14 is a typical day of the system responding to the frequency smoothing signal that was generated from the real time frequency measured at the test site. As can be seen, the performance of the system in Figure 14 is much better than that of Figure 13. For virtually all 24 hours, the system responded exactly as requested, with very little time during which the system was out of energy.

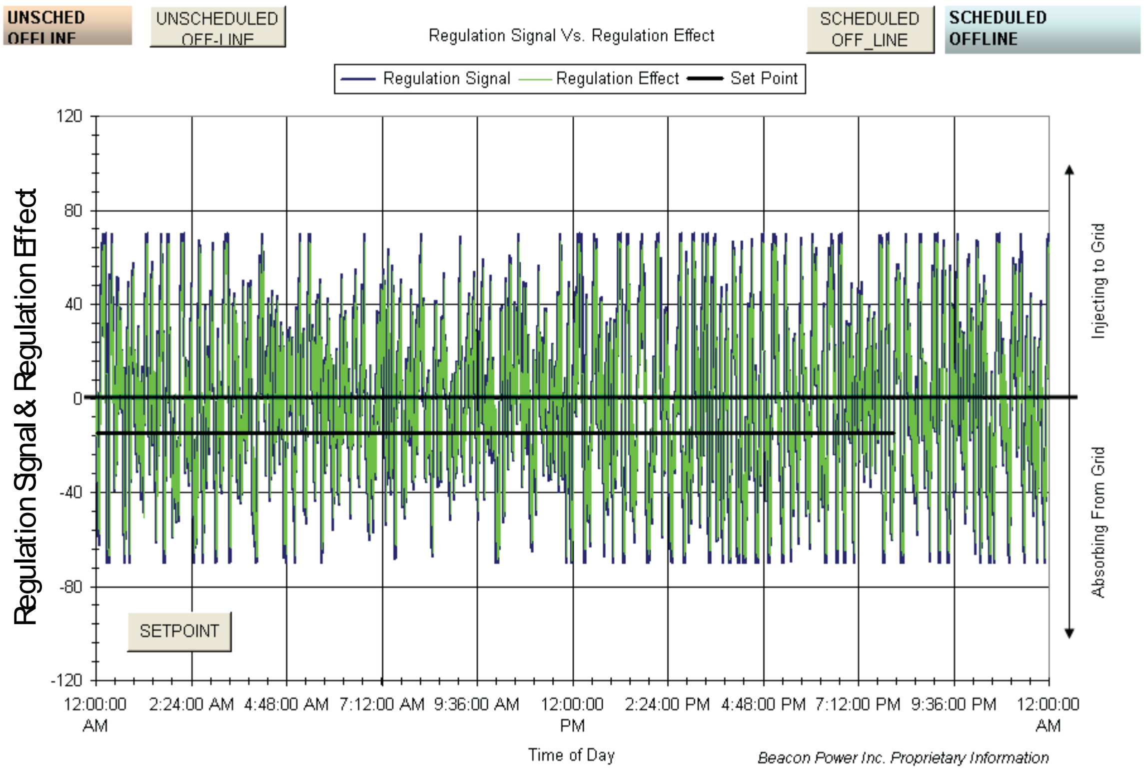


Figure 14 - Typical response generated from smoothed frequency signal

The official portion of the field trial test was performed from July, 2006 to February, 2006. During this time, data was collected 24 hours a day to determine how the system was performing doing frequency regulation. Each day, the data was downloaded and the amount of time the system was in each of the following four categories was summarized.

1. Frequency regulation- Time actually following a regulation signal
2. Energy depleted – unable to follow the signal
3. Scheduled off-line – Time to reset conditions or perform maintenance or system upgrades
4. Unscheduled off-line – Time the unit was offline unexpectedly due to a system problem

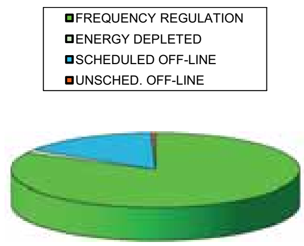
The sum of items one and two above make up the on-line time, which has three additional performance metrics that are shown in Figure 15. First, the percent of time the system was performing per regulation and following the signal. This is referred to in Figure 15 as Availability. The second metric is Deviation, which is a measure of how close the actual output tracks the requested signal. It is first calculated excluding the time the system was out of energy. Then it is recalculated while including this time.

The system was performing per regulation between 60 % and 84 % of the time it was installed. There was very little unscheduled off-line time. The majority of the time, the system that was not performing per regulation was either scheduled off-line or depleted of energy. During July through December there was significant time when the system was depleted of energy. Like the example in Figure 13 above, the signal generated during this time (from measured frequency) requested the system to inject energy for extended time (usually greater than 30 minutes). Starting in January, we modified the signal to reflect frequency smoothing as shown in Figure 14 above, and the energy depleted time went down to 3 % in January and 2 % in February. This is a key result as it identified the type of signal that the flywheel system can follow for the best system benefit. It allows the ISO to use the flywheels to respond to fast changing imbalances and to use regular generators to respond to the slower / long duration imbalances. As can be seen in February, once the system was optimized, it was available to perform regulation 96.8 % of the time it was on-line.

The average scheduled off-line time was 12 %. This included the time the system was off-line for planned events such as changing the test conditions. If the system had an unplanned outage it was charged with one hour of unscheduled off-line time, then scheduled offline until repaired. This is because in a production environment the system would be pulled out of the open market until repaired. Any event that resulted in unscheduled off-line time received greater scrutiny to determine the root cause and corrective action. These items were then summarized and used to establish the lessons learned for the product, which are shown in section 4.2.

NYSERDA Run Data Monthly Summary Sheet **Date:** **July 06 - Feb 07**

		July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Average
DAILY SUMMARY	FREQUENCY REGULATION	73%	75%	80%	84%	84%	71%	81%	81%	76%
	ENERGY DEPLETED	9%	12%	13%	11%	11%	10%	3%	3%	9%
	SCHEDULED OFF-LINE	18%	12%	7%	4%	4%	18%	15%	15%	12%
	UNSCHED. OFF-LINE	0%	1%	0%	0%	0%	1%	1%	1%	0%
	Total	100%	100%	100%	100%	100%	100%	100%	100%	100%
ON-LINE PERFORMANCE	Availability = Freq Reg / 24 Hrs minus Scheduled Off-line Hrs	88.9%	84.9%	85.6%	89.0%	87.7%	87.2%	95.6%	96.8%	89%
	Deviation Excluding Depleted Time	2.7%	3.6%	2.2%	2.6%	6.9%	2.7%	5.8%	2.4%	4%
	Deviation Including Depleted Time	7.9%	10.4%	7.9%	7.1%	10.5%	7.1%	7.0%	3.4%	8%



DAILY SUMMARY

Figure 15 - Summary of System Performance

Additional details of the performance test data are included in Appendix 8.8

On December 20, 2006, the system was set up to demonstrate the system's ability to provide reactive power and to impact the power factor of a local facility such as PCT. The data that is shown in appendix 8.5 demonstrates the ability of the Smart Energy Matrix to improve PF (Power Factor) of an industrial facility and to supply reactive power of any character (inductive and capacitive) in the industrial environment.

The Smart Energy Matrix responded remotely and was able to change the PF of the facility in the range from 0.8 to 0.98 and inject up to 54 kVAr of inductive and up to 57 kVAr of capacitive reactive power. This represents approximately 50% of the Smart Energy Matrix capabilities.

4.2. Lessons from Demo being applied to Product 20 MW system

One of the main objectives of the project was to collect data to design the product flywheel frequency regulation system. At the start of the demonstration projects, the product was envisioned to be a module of 10 flywheels, which would produce 1 MW of regulation. These would be distributed throughout a control area. During the course of the project, as we discussed this concept with the ISO, DOE, various utilities, and finance organizations, it was concluded that larger systems would provide more benefit with less cost per unit of regulation. After other considerations, such as the interconnection and permitting process, it was determined that a 20 MW Flywheel Regulation Facility would be the baseline. The following table is a summary of some of the knowledge gained during the demo project that is being applied to this facility design, which is now considered the commercial product.

Issue	Lesson / Product Change
Electronics Reliability less than product requirements	Increase design margin on components - Improve supplier management - Increased testing - Plug and play components
Motor leads damaged due to High Voltage Corona	Corona resistant materials - Improve wire routing - Incorporate controls on vacuum level
Plant equipment reliability (Load bank and Chiller)	Vendor selection and component qualification - Redundancy on critical systems - Eliminate unnecessary systems and components
Epoxy failure on hall sensor (timing sensor)	Hall sensor eliminated - Sensor-less control implemented
Software Control	In house test simulators planned to check software changes
Signal Monitoring	24 hour live monitoring - Watchdogs on each connection - Auto reset required
Contactor Reliability - Controlled by master controller - Single Point failure affects entire system	Separate control from master controller - Eliminate single point failures that affect the entire system
Control signal development	System best suited to follow signals that cross zero often, such as ACE smoothing as compared to conventional AGC signal. This is also the most useful for the ISO and the system, because if the flywheel responds to the fast changing imbalances, then generators can more easily deal with the slower changing imbalances.

Table 1 - Lessons from Demo being applied to the Product 20 MW System

4.3. Commercialization plan

4.3.1. 20 MW Frequency Regulation Plant Design

During the course of the demonstration project, as we discussed regulation services with the ISO, NYSERDA, DOE, various utilities, and finance organizations it was concluded that larger systems would provide more benefit with less cost per unit of regulation. After other considerations, such as the interconnection and permitting process, it was determined that a 20 MW Flywheel Regulation Facility would be the baseline. A separate project was funded by DOE under Sandia National Labs (contract 611589) to design such a facility. Figure 16 shows the baseline concept for this facility.

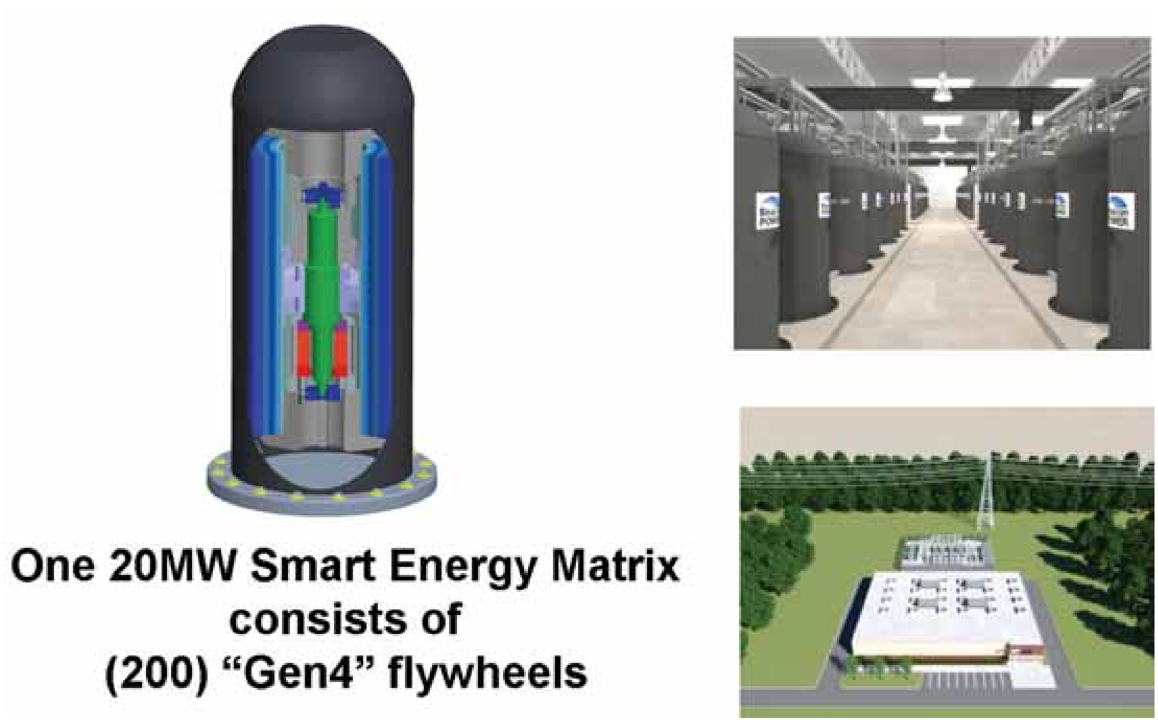


Figure 16 - Concepts for a 20 MW Flywheel Facility for Grid Frequency Regulation

4.3.2. Emissions Analysis

As part of the above contract, KEMA Inc. was commissioned by Beacon Power to evaluate various performance aspects of the Beacon Power 20 MW flywheel-based frequency regulation power plant, including its emissions characteristics. To support the emissions evaluation, a detailed model was created to compare the emissions of CO_2, SO_2 and NO_x for a Beacon Power flywheel plant versus three types of commercially available power generation technologies used in the market to perform frequency regulation ancillary services. Table 2 below summarizes the projected emission savings if applied to other technologies applied to the PJM system. A similar result would be expected if this analysis was done on the NYISO.

Table 2 - Emissions Comparisons for PJM

Flywheel Emission Savings Over 20-year Life: PJM					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	149,246	149,246	149,246	149,246	149,246
Alternate Gen.	308,845	616,509	194,918	224,439	202,497
Savings (Flywheel)	159,599	467,263	45,672	75,193	53,252
Percent Savings	52%	76%	23%	34%	26%
SO2					
Flywheel	962	962	962	962	962
Alternate Gen.	2,088	5,307	0	0	1,305
Savings (Flywheel)	1,127	4,345	-962	-962	343
Percent Savings	54%	82%	n/a	n/a	26%
NOx					
Flywheel	259	259	259	259	259
Alternate Gen.	543	1,381	105	154	351
Savings (Flywheel)	284	1,122	-154	-105	92
Percent Savings	52%	81%	-148%	-68%	26%

Figure 15, below, shows these results in graphical form. For a more detailed description of the model used and assumptions in this analysis, see the KEMA report in Appendix 8.8.

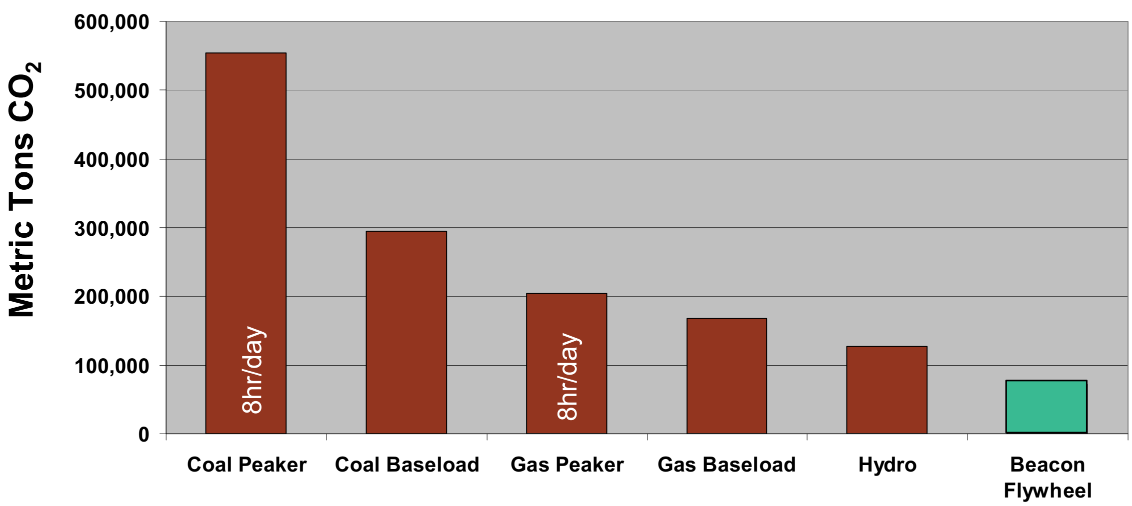


Figure 17 - Emissions over a 20- year operating life

4.3.3. Cost Performance Analysis

As part of the Sandia National Labs contract above, KEMA, Inc. was commissioned by Beacon Power, to evaluate various performance aspects of the Beacon Power 20 MW flywheel-based frequency regulation power plant, including its life cycle cost to perform frequency regulation ancillary services in three Independent System Operator (ISO) markets. To support this evaluation, a model was created by KEMA to compare the life-cycle cost of the Beacon Power flywheel plant with four types of commercially available fossil power generation technologies used to perform frequency regulation services. The flywheel system was also compared with a lead acid battery storage system that could also be used to perform frequency regulation ancillary services, similarly to the flywheel system.

The analysis included preparation of a Life Cycle Cost model using Net Present Value analysis that reflected fixed and variable costs for regulation. As can be seen in Figure 18, Beacon Power's flywheel is capable of delivering the regulation services at the lowest life cycle cost.

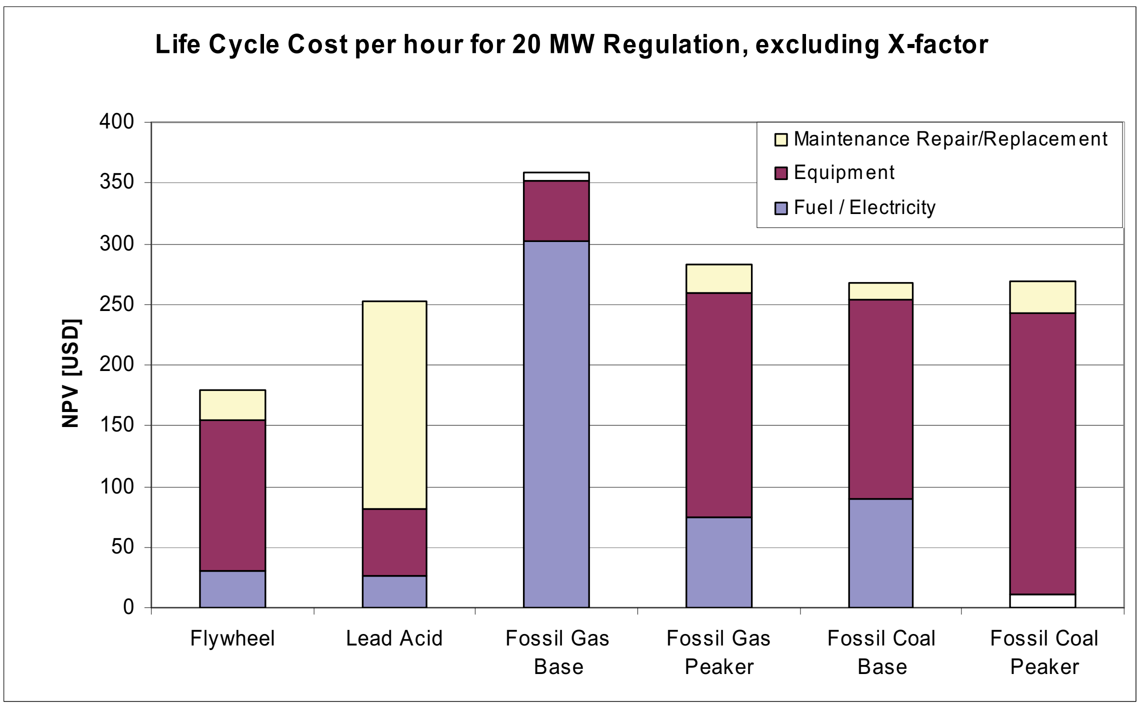


Figure 18 - Life Cycle Cost per hour for 20 MW Regulation

In addition to the above analysis, Beacon performed additional return on investment analysis that reflects both expected revenues and costs for a 20 MW plant over a 20-year period. The following assumptions were included:

Plant Life [1]	20 years
Plant Cost [2]	$32,660,400
Termination Value [3]	0
Revenue per MW-hr	$50.00

Revenue Escalator	3% per year
Equity Percentage	30%
Investment Tax Credit	None
Corporate Tax Rate	37%
Depreciation Schedule MACRS (Modified Accelerated Cost Recovery Schedule)	MACRS 7-year
Long-term Debt Period	15 years
Long-term Debt Rate	10%
Construction Period	8 months
Average Construction Loan Balance	30%
Construction Debt Rate	10%
Energy Make-up	39 MWh per day
Cost of Make-up Energy	$75 per MWh
Energy Cost Escalator	2% per year
Plant Repair [4]	$261,000 per year
Property Taxes [4]	$165,400 per year
Labor [4]	1.5 FTE
Insurance [4]	$75,000 per year
Building Maintenance & Other Utilities [4]	$46,000 per year

Notes:

1) Plant Life assumed to be 20 years; in practice, expected life greater than 20 years.
2) Plant Cost includes: flywheels, electronics (ECMs), grid infrastructure improvements, land, building, balance-of-plant, freight, interconnection study, legal, accounting, construction financing.
3) Termination Value: assumed to be zero; in practice, the plant should have a positive termination value if its useful life is greater than 20 years.
4) Annual Operating Cost Inflation Rate: assumed to be 3%.

4.3.4. Commercialization timeline

The following shows a preliminary schedule of how Beacon plans to proceed with commercializing flywheels to enter the frequency regulation market. The details of this plan will be subject to change based on market prices, available financing, and approval of the required agencies.

ID	Task Name	Duration
1		
2	**Plant Location and Siting**	437 days?
3	ISO Certifications - NY, CA, PJM, (NE)	150 days
4	Bi-Lateral Contract Negotiations	150 days
5	Site Evaluations	90 days
6	First Site Selection	0 days
7	Site Contract Negotiation	60 days
8	Interconnection Feasibility	35 days
9	Interconnection Cost +/- 25%	60 days?
10	Interconnection Balance of Process	145 days
11		
12	**Flywheel Production**	502 days?
13	25 kWh Development	172 days
14	Full Power Full Speed	22 days?
15	Electronics Qualification	33 days?
16	Saftey Testing	43 days?
17	Order Long Lead Components	80 days
18	First MW Module	130 days
19	100-200 Flywheel Build	220 days
20		
21	**20 MW Plant Design Construction**	420 days
22	Baseline Plant Design	128 days
23	Plant Financing	110 days
24	Site Specific Design	30 days
25	Plant Build	150 days
26	First Revenues	0 days
27	Add Additional Flywheels	140 days

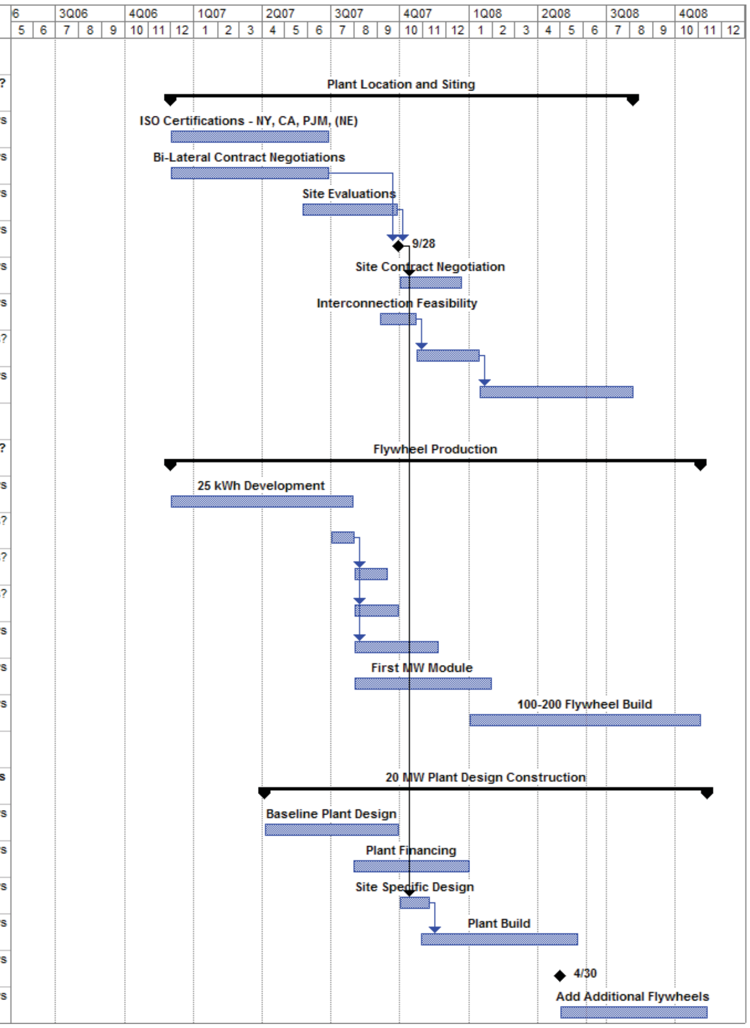


Figure 19 - Commercialization Time Line

4.4. Project Status Vs. Objectives

The following table shows the original project objectives and a status for each objective. In summary, all program objectives were met and this demonstration project has served Beacon and the sponsoring agencies in a number of ways. The original plan called for 18 months of durability testing, however, after eight months it was determined that enough data had been collected to evaluate the system performance. This agreement was reached with Joe Sayer of NYSERDA and Georgianne Peek of Sandia and is documented in Appendix 8.3 as an amendment to the test plan. Focus has now been moved to detail design of a commercial regulation system. Data from the project has been used to help develop our next generation flywheel, which is a 25 KWh/100kW energy storage module. Based on the early success of the project the DOE thru Sandia National Labs awarded a follow- on contract to design a 20 MW Flywheel Frequency Regulation Plant, which would house 200 of the generation-4 flywheels. In addition to the knowledge being used for design of our commercial system, it has helped Beacon develop a relationship with the utilities, NYSERDA, NYISO, NYSEG and other stakeholders that will be needed to fully commercialize a system.

Table 3 - Project Status vs. Objectives

Objective	Status
Proof of concept on ~1/10th power scale	100kW demonstrated vs. 1 MW Module. Product now twenty (1 MW) modules
Show ability to follow fast changing Frequency Regulation signals	Response time of four seconds demonstrated. See data
Demonstrate anti-islanding	Complete- Using standard Beckwith Relay
Validate interconnection capability	Connected to grid with no adverse impact. Beckwith protective relay demonstrated system is disconnected in <2 seconds after grid outage.
Demonstrate performance & economic value	System Performance demonstrated. Economic value established.
Develop and demonstrate communications with grid operators	Communications system demonstrated. Improvements defined for product.
Collect data for product specifications	Data collected and being used for Product Design
Report results - Gain industry confidence	Site demonstrations to key stakeholders- Extensive data distributed to all stakeholders.

5.0 Conclusions

The demonstration project accomplished all of its original objectives. The data, lessons and stakeholder interactions have demonstrated that using fast acting energy storage is a viable method to perform grid frequency regulation. The benefits have been quantified and data has been shared and validated by all stakeholders. The demonstration project was a key step in moving the concept of Frequency Regulation using Flywheel Energy Storage from a concept to detail design of a commercial 20 MW facility. A representative of the NYISO reviewed the data and concluded the flywheel technology to be acceptable and viable for use in the New York ISO grid frequency regulation system.

6.0 Recommendations

In order to obtain the maximum benefit of fast acting regulation services using Flywheel Energy Storage in NY, additional integration is required with the NYISO. Initial discussions with the ISO are centered on building a 20MW flywheel facility to perform regulation services as a direct replacement for current generators. In order to fully make use of the benefits of fast- acting regulation, a non-generator regulation service should be established. This would establish market rules to take advantage of the fast response, while modifying the rules that are currently written to be compatible with existing generators that provide energy and regulation under the existing rules. NYISO is working on a Demand Response program; however this is for all ancillary services, and is not specific to fast responding regulation providers. A separate service that covers fast acting, regulation-only services, could provide benefits to ISO, its customers, and eliminate unnecessary constraints to the providers.

7.0 Benefits to NY

The demonstration project validated the benefits cited in the original proposal and further quantified these benefits. If a 20 MW Flywheel facility were installed in NY it would provide the following benefits:

- Increase the supply of competing regulation service providers. Some estimates indicate regulation provided by fast acting energy storage would be twice as effective as the current resources. [1] As more of this type of regulation is added the total MW of regulation procured should be reduced, thereby reducing the total cost to the NY electricity consumers. In addition, as more renewable energy resources are added to meet the renewable portfolio standards additional regulation resources are expected to be needed. The addition of a Flywheel Energy Storage Regulation plant would help offset this increase in demand.
- As the studies in Section 4 indicate, a significant reduction in Emissions of CO_2, SO_2, and NO_x are expected if a 20 MW Flywheel regulation plant were to be installed in NY.
- As Flywheels are used to perform regulation services, the units currently performing regulation could be used in the energy market, thus increasing the available capacity without adding additional generators.

[1] Reference December 2006 press release from the California Energy Commission citing work done at Lawrence Berkeley national laboratories.

8.0 Appendices

8.1. Control System Design

8.2. Acceptance Test Report

8.3. NYSERDA Field Trial Test Plan

(Including agreement to conclude testing after 8 months)

8.4. Press Release – Quotes from NYISO & NYSERDA

8.5. Reactive Power Injection Report

8.6. Emissions Analysis Report

8.7. Cost Performance Report

8.8. Detailed Data for Field Trial Test

8.9. DOE Independent Evaluation of Data

(Reference 4th qtr 2007 ESAT Presentation by EnerNex)

Appendix 8.1.
Control System Design

December 22, 2005

Joseph Sayer,
NYSERDA
Senior project Manager
Transportation and Power Systems Research

Subject: Control System Design (Ref task 4 deliverables for contract 8719)

The attached document summarizes the control system and algorithms for flywheel energy storage system to be provided under the above agreement. As described the initial testing will demonstrate the ability of the system to respond to variations in the grid frequency as measured at the test site. The system can be programmed to provide reactive power or real power output. A more detailed test plan will be created and reviewed prior to shipment of the system from Beacon. If you have any questions please give me a call.

Sincerely

Jim Arseneaux
Director – Flywheel and Mechanical Products.
Beacon Power
(978) 694-2097

CC
Georgianne Peek

NYSERDA Project

Project 8719 Grid Frequency Regulation By Recycling Energy in Flywheels

Control System Design
December 22, 2005

Beacon Power Corporation
234 Ballardvalle St.
Wimington, Mass. 01887

**(Relocated to 65 Middlesex Rd.
Tyngsboro, Ma, 01897 in Jan 2008)**

Contents

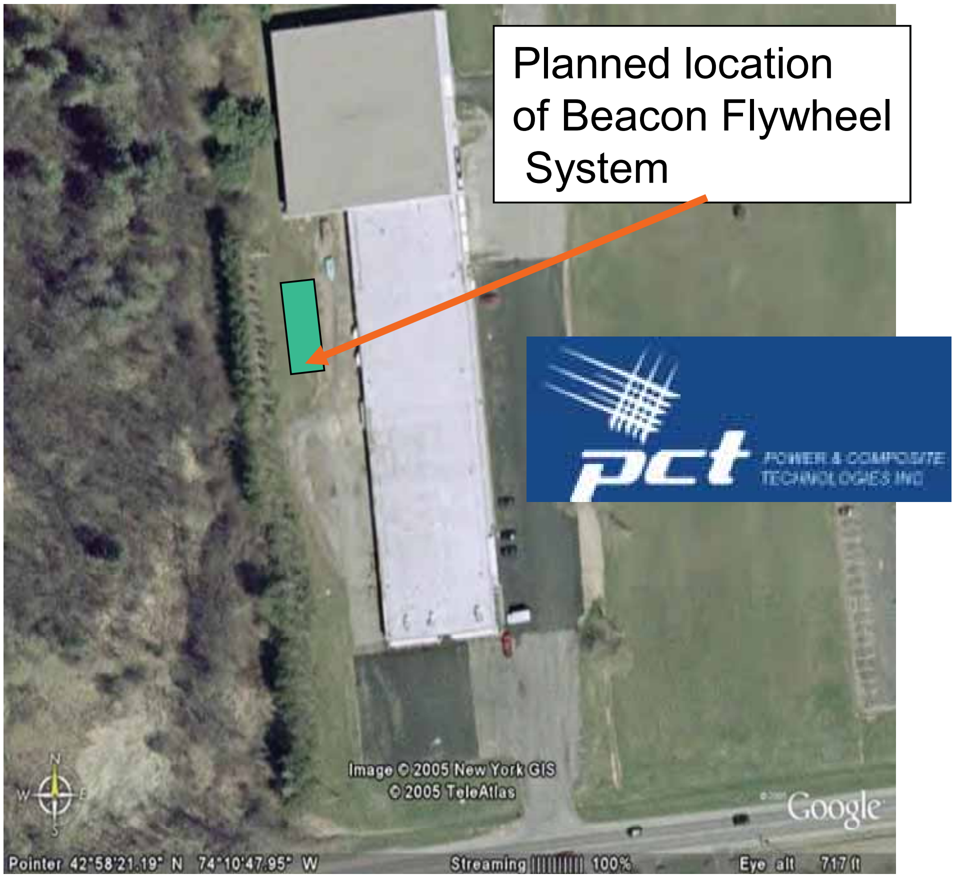
Background

The energy storage system designed for the reference project consist of 7 flywheel systems installed in an 8’ X 20’ shipping container. The complete system is referred to as a demonstration SEM (Smart Energy Matrix.) The following are outside and inside views of the demonstration SEM.

Outside View

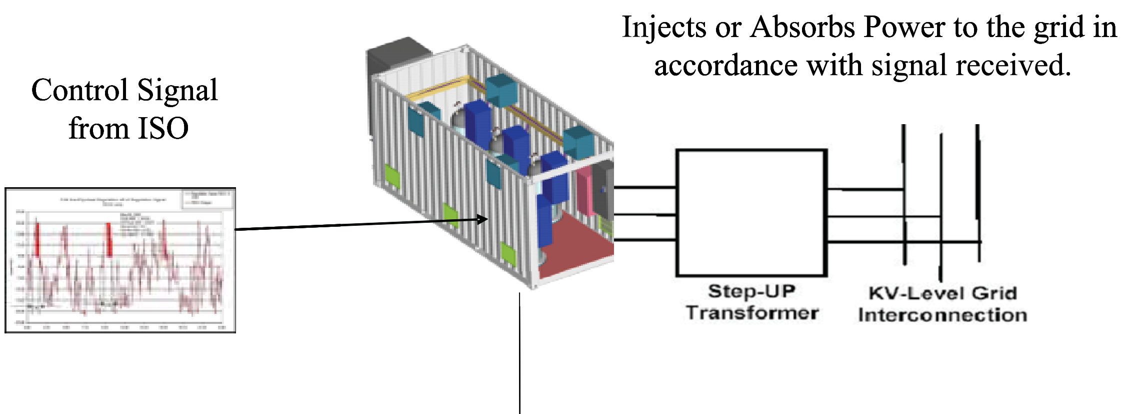
Inside View

The system will be installed at PCT (Power & Composite Technology) in Amsterdam, New York. The following shows the planned location.



System Operation

In its simplest form the SEM is a box which stores and releases energy to and from the grid. It will absorb or inject power from the grid in response to a control signal. There are only two connections to the system. The first is an internet connection which will transmit control signals to the system. It will also allow transfer of test data from the SEM to various sites and allow limited external access through the internet to adjust system operating parameters. The second connection is a 480 Vac connection to a transformer which connects to the high voltage transmission line. These connections are shown schematically in the figure below.



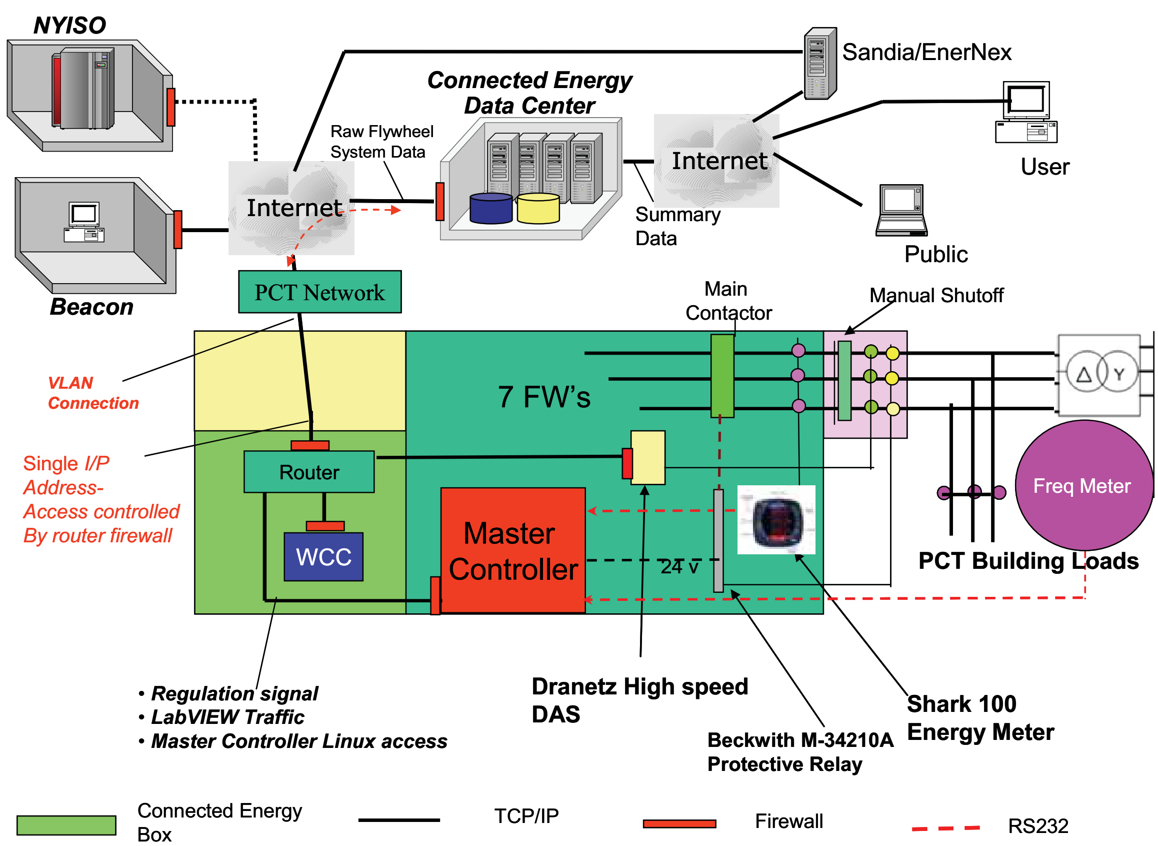
Smart Energy Matrix (SEM)
or
(Integrated Grid Responsive Energy Storage System)

The Control Signal directs the system to inject or absorb power. Initially the system will respond to the variation in the grid frequency. Later the system may be configured to respond to a signal from the NYISO.

Network Connections

As indicated there is one network connection, which will be tied directly into the PCT computer network. Access to connect via the internet to the SEM will be limited by passwords and firewalls located within the SEM. The following schematic shows the various locations that will be allowed access to the system.

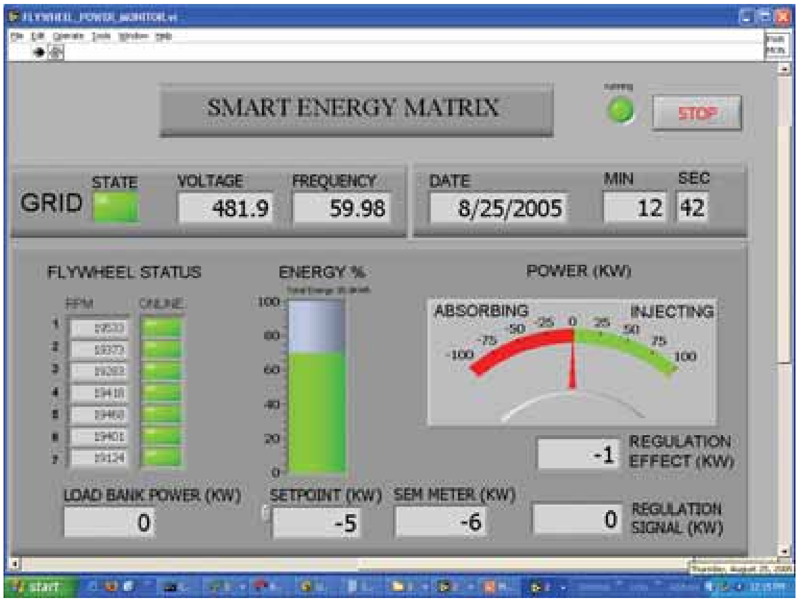
Communication and Control Schematic.



EMS

Beacon Power Network Access

Beacon will have access via the internet to the master controller and the Dranetz high speed Data Acquisition System. With this Beacon can change all system operating parameters and set-points. Beacon will have 2 Graphical User Interfaces to monitor the system and change set-points. These two user interfaces are shown below.



The above User Interface summarizes the system level data. It shows Flywheel speeds, grid status, system energy level and current power being absorbed or injected.

This interface provides detailed operating data about each flywheel. This will be used to monitor individual flywheel performance and adjust operating set-points.

NYISO Connection

As stated above, initial testing will be performed with the SEM responding to measurements from the local frequency meter. In the future, if we want to follow commands from the ISO, they will be sent via a secure internet connection.

Connected Energy Data

Connected Energy is a subcontractor on this project and is responsible for communications between the outside organizations and the SEM. They have provided a PICS 501 router, which limits access to the system. Connected Energy will have access to change router settings and to the Web Communications Center within the SEM. Data from the Master Controller is sent to the Connected Energy Data Center for Storage and processing. Select data will be plotted and summarized. Anybody with internet access (shown as public) and a username and password will be able to view summarized data. From the Data Center alarms can be set based on operating parameters and a text message sent to assigned personnel who could then log in and perform any required troubleshooting and/or take corrective action.

Sandia/EnerNex Connection

EnerNex Corporation is subcontracted by DOE to collect system data and provide an independent assessment of the SEM operation. A Dranetz Dual Node 5500 High Speed Data Acquisition System is installed at the SEM point of connection. EnerNex will have internet access to program the DAS system remotely and collect and store data from this system. It can be compared to or used in conjunction with data at the Connected Energy Data Center. This data will also be accessible by the public.

Internal Control

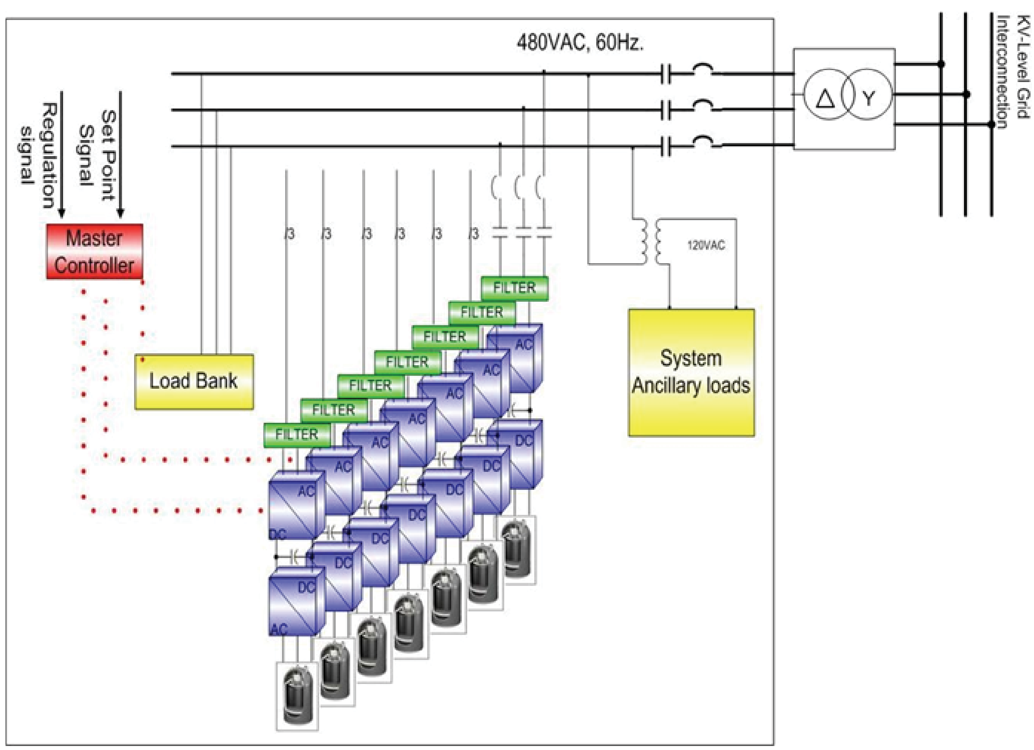
Inside the SEM there is an industrial PC which receives the regulation signal, monitors system operation and provides commands to the Load Bank and Flywheels to meet the required level of power injection or absorption.   This computer and its associated hardware is referred to as the Master Controller. The following shows a picture of the Master Controller.

←Web Communication Center

←Master Controller

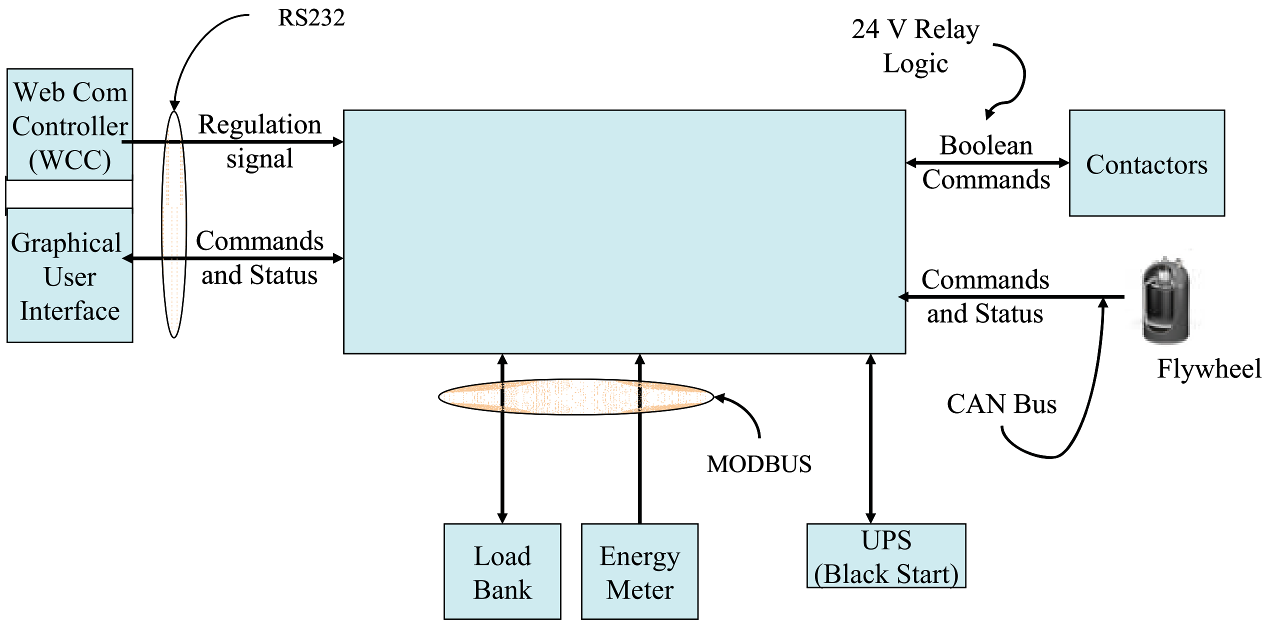
←UPS
(Provides Backup Power to MasterController so communication Can be maintained without grid.)

The Schematic Below shows the components being controlled by the Master Controller.



Master Controller Inputs and Outputs

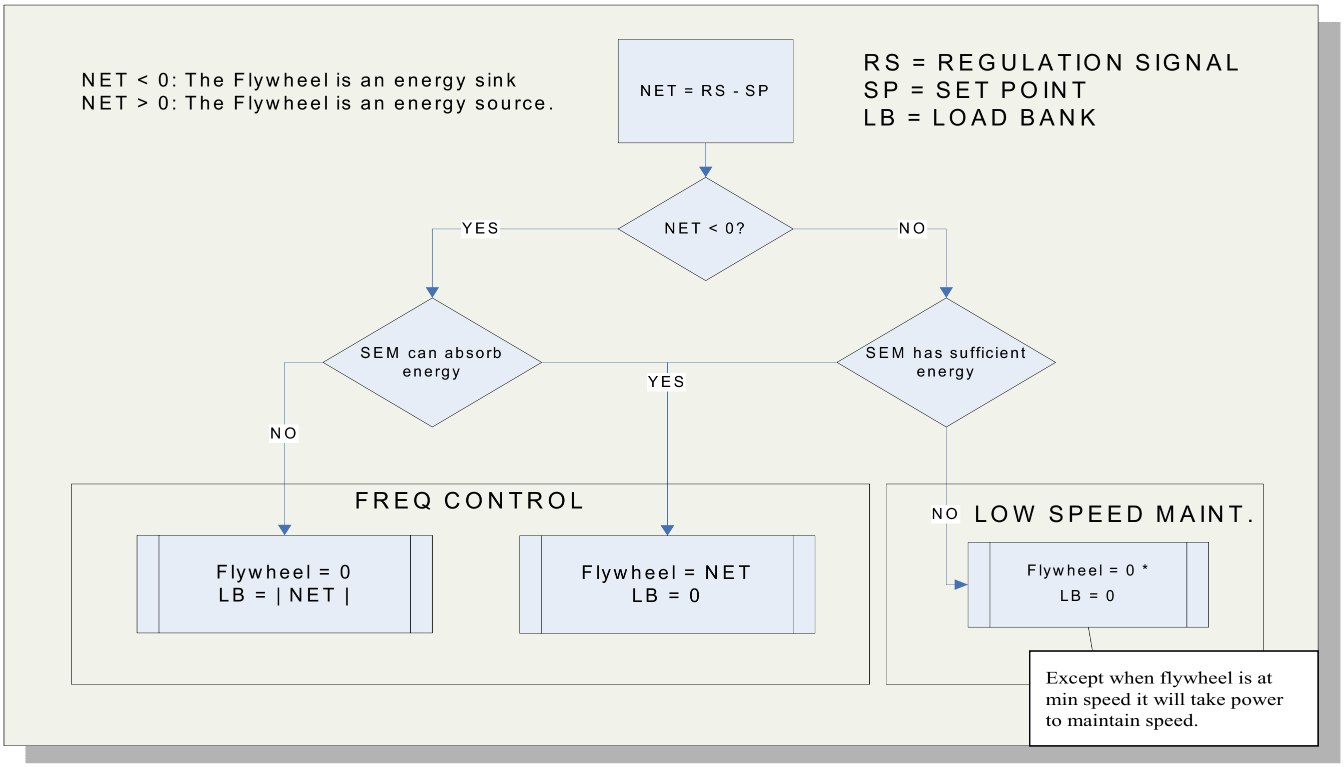
The figure below shows the inputs and outputs for the Master Controller.



The main goal for the Master Controller is to send power commands to the load bank and flywheels to meet the overall power request for the system. It's secondary functions are state of health monitoring, and command / status processing.

Master Control Algorithm

The algorithm below is a simplified schematic of the main loop in the master controller. Based on the regulation signal and set point the algorithm determines how much power and in what direction to command the flywheels and load bank. It then sends the load bank command via an RS232 serial port, and the flywheel commands via optical cable.

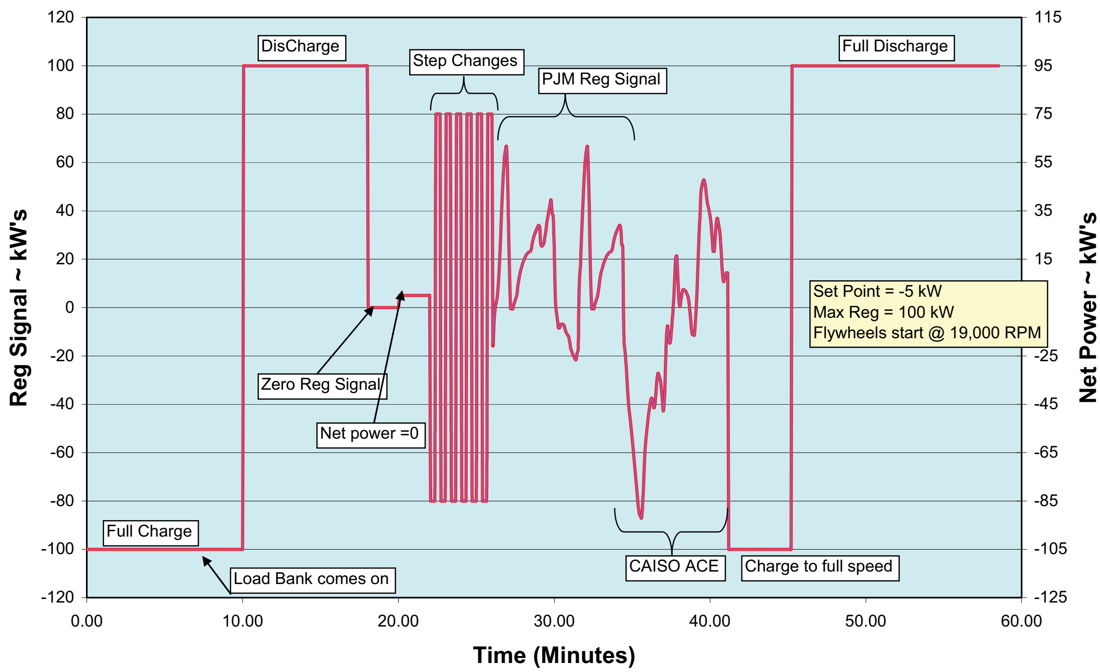


Planned Control Testing

Prior to shipment Beacon will test the system to assure it can follow the required control signals and that the Master Controller algorithms have been validated. On site testing will be focused on ability of the system to follow real and reactive power control signals when commanded.

Real Power Control Signal

Test data from CEC indicates outstanding ability to follow any signal we provide to the SEM. A typical test signal is shown below.



The plan for the NYSERDA demonstration is to respond directly to grid frequency variation. Response will be proportional to frequency deviation from 60 hz. There will be a frequency monitor with ModBus installed to feed frequency to master controller. Based on this signal the Master Controller will determine the amount of power to command. It will inject or absorb100kW at 2 sigma frequency variation. If frequency is high it will absorb power and if it is low the system will inject power. Based on test results we consider whether other real power command signals should be tested. If so they will be a zero to 100kw signal transmitted across the internet connection.

Reactive Power Control Signal

The following functionality has been added to the system (relative to the base CEC system):

- Four quadrant operation incorporated into all seven Electronic Control Module.
- The master controller has a new parameter which controls the reactive power component separately.
- Initially we can demonstrate ability to vary real and reactive components on command using manual commands.
- We will establish reactive power needs of PCT during power quality audit.
- We could incorporate feedback into the control system to demonstrate the ability to compensate for reactive power changes in real time. This would be additional work-scope and may suggest possible follow on effort.

Summary

This report summarizes the baseline control system and algorithms as required by Task 4 contract deliverable. Beacon Power can provide additional details as required by program participants. Updates to the system will be documented in an operating manual, which will ship with the system. More detailed test plans will be reviewed with the NYSERDA project manager prior to shipment.

Appendix 8.2
Acceptance Test Report

BPC-0011-06-TP

BEACON POWER SMART ENERGY MATRIX DEMONSTRATION UNIT #2

PRE-SHIPMENT ACCEPTANCE TEST REPORT

NYSERDA Agreement Number
8719

30 March 2006

Prepared for
New York State Energy Research and Development Authority

Prepared by
David R. Lundell, Sr. Test Engineer
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234 Ballardvale Street
Wilmington, Massachusetts 01887

(Relocated to 65 Middlesex Rd.
Tyngsboro, Ma, 01897 in Jan 2008)

Table of Contents

1. Scope

This document describes the tests performed by Beacon Power on the 100 kW Demonstration Smart Energy Matrix (SEM) prior to delivery to the installation site in Amsterdam, New York. This completes Task 7 of the Statement of Work for Agreement 8719. Refer to Appendix A for the original Test Plan document.

2. Communications

Internet – Connected Energy Web Communications Controller (WCC)

- Communications were verified between the WCC in Wilmington MA and the Connected Energy Data Center in Rochester, NY.

Internet – Beacon Master Controller

- Communications were verified between the SEM Master Controller in Wilmington MA and remote locations via the Internet.

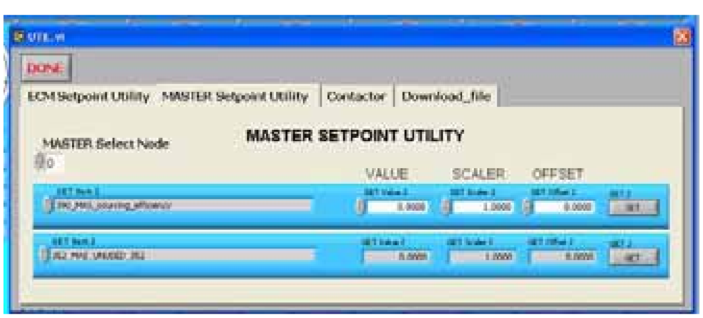
3. User Interface

Contactor Closures

- Main, Load Bank, and Energy Control Modules (ECM) contactor closures were initiated from the “Utilities tab.

Master Controller Setpoints

- All Master Controller setpoints are established and documented.



Parameters Displayed Properly

- SEM parameter displays correct.
    a) Flywheel Speeds
    b) Active Rectifier Currents
    c) Motor Currents
    d) Internal Bus Voltages
    e) Top and Bottom Balances
    f) Bearing Temperatures
    g) Motor Temperatures
    h) Rim Temperatures
    i) Vacuum Heaters
    j) ECM Contactor States
    k) Grid Contactor State
    l) Grid Voltage
    m) Grid Current
    n) Grid Frequency

Master Controller RS-485 Communications

- Communications and control between the SEM Master Controller and the Load Bank via RS-485 was verified.
- Communications between the SEM Master Controller and the Energy Meter via RS-485 was verified.

4. <u>Interconnection Testing w/o Flywheels Operating</u>

Check Protective Relay Settings

- CEC SEM Beckwith protective relay settings file were downloaded to NYSERDA protective relay and checked via the relay communications port.

SEM Voltage and Current Measurement

- Protective relay measurement of voltage and current verified.

Protective Relay Disables Main Contactor

- Beckwith Protective Relay disabled SEM Main Contactor upon loss of utility power (main power switch was opened)

Reconnect Time

- Protective relay inhibited reconnection of SEM for 320 seconds after utility power returned (main power switch was closed.)
  IEEE 1547 requirement - >300 seconds.

5. System Mechanical Checkout

Chiller Operation

- Chiller on after Main Contactor closure. Chiller maintains flow at correct pressure (50 psi) and temperature (20C).

Charge Flywheels

- Seven flywheels charged to maximum speed – no faults

Load Bank Operation

- Load bank absorbs excess power after flywheel level-of-charge exceeds power absorption demand.

Discharge Flywheels

- Seven flywheels discharge to minimum speed upon discharge commands.

6. Disconnect Test with Flywheels Operating

Ability to Disconnect with Flywheels in Charge or Discharge Mode

- SEM main power was disconnected at full power charge state and full power discharge state – contactor opened as required and was reclosed w/o issue.

7. Normal System Operation

Automatic System Startup Sequence on SEM “ON” Command

- “ON” command via SEM User Interface starts and accelerates each flywheel sequentially, such that no flywheel critical speeds intersect and proceed to programmed speeds.

Data Systems Operational

- Connected Energy Data Acquisition System (DAS) utilizing SEM Energy Meter is functional.
- Enernex is communicating with Dranetz DAS in Amsterdam, NY.

SEM Following Signals

- SEM follows slave signals from local and remote computers via network and internet connections
- SEM follows baseline test signal – refer to Appendix B
- SEM follows simulated dynamic frequency signal derived from frequency data from Dranetz at Amsterdam NY – refer to Appendix C

8. Reactive Power Demonstration

- SEM responds to manual commands via User Interface to provide injection or absorption of different levels of reactive power – refer to Appendix D

9. Normal Shutdown

- "STOP" command via SEM User Interface decelerates each flywheel sequentially, such that no flywheel critical speeds intersect and proceeds to zero RPM.

10. Connected Energy Data Center On-line

- All data is transmitted to Connected Energy Data Center and selected data is displayed and can be retrieved from an ENERVIEW webpage. Refer to Appendix E

Appendix A – Original Test Plan

NYSERDA Flywheel System Test to be performed at Beacon

February 24, 2006

- Communications
  - Verify communication via internet to Connected Energy "Comsys" box
  - Verify communication via internet to Beacon Master-controller

- Verify all new User Interface functions are working
  - Contactor Closure
  - Master Controller Set points
  - All Parameters being properly displayed.
  - Ability to communicate with Energy Meter and Load Bank

- Interconnection testing *without* flywheels operating
  - Check Beckwith settings
  - Turn on 480 Vac power
  - Activate main contactor with GUI
  - Verify proper voltage and current to system
  - Verify Beckwith disconnects main contactor upon loss of utility power.
  - Validate settings per 1547.

- System mechanical checkout
  - Charge Flywheels
  - Load Bank Operation
  - Discharge Flywheels

- Interconnect testing with flywheels operating
  - Verify disconnect with flywheels operating in charge or discharge mode

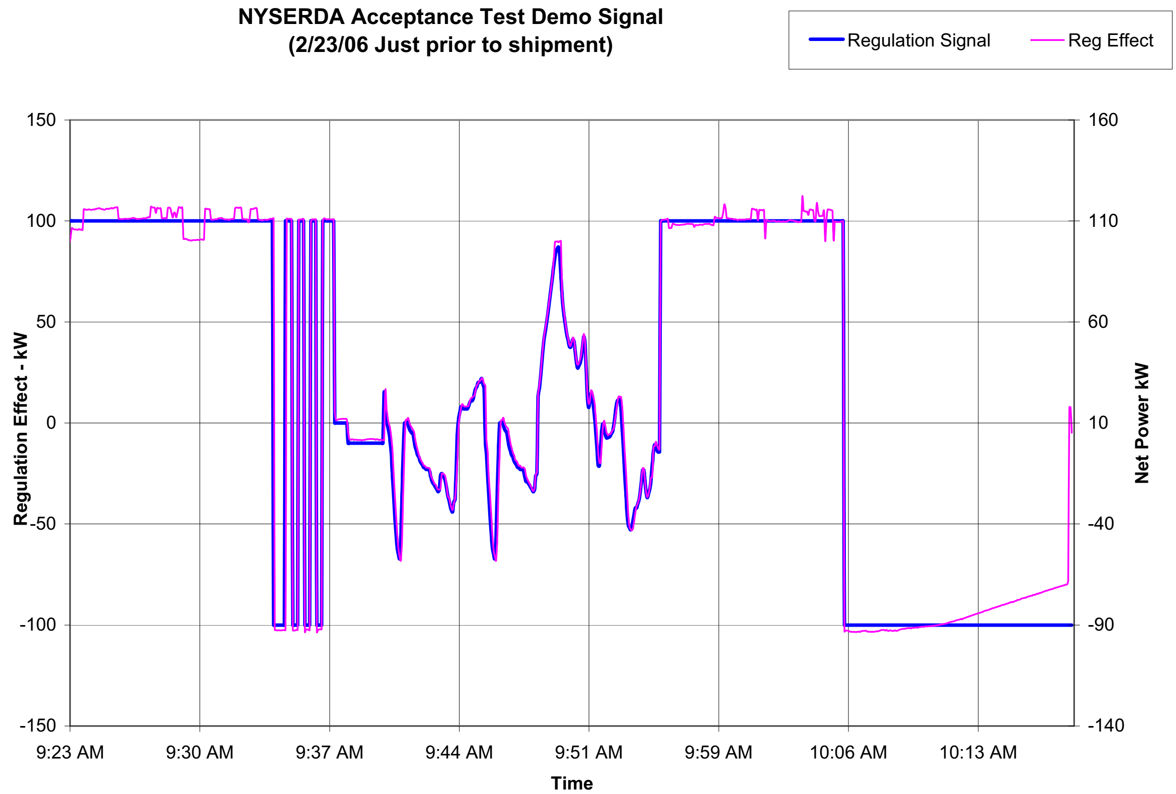
- Normal System Operation
  - Verify system startup sequence on command
  - Verify all data systems operating
  - Follow slave signal from laptop on site
  - Follow slave signal from remote sight
  - Follow baseline signal test signal (See Figure 1)
  - Follow simulated Frequency Signal (See Figure 2)

- Verify all Data being communicated to Connected Energy Data Center and being displayed on Web Page.

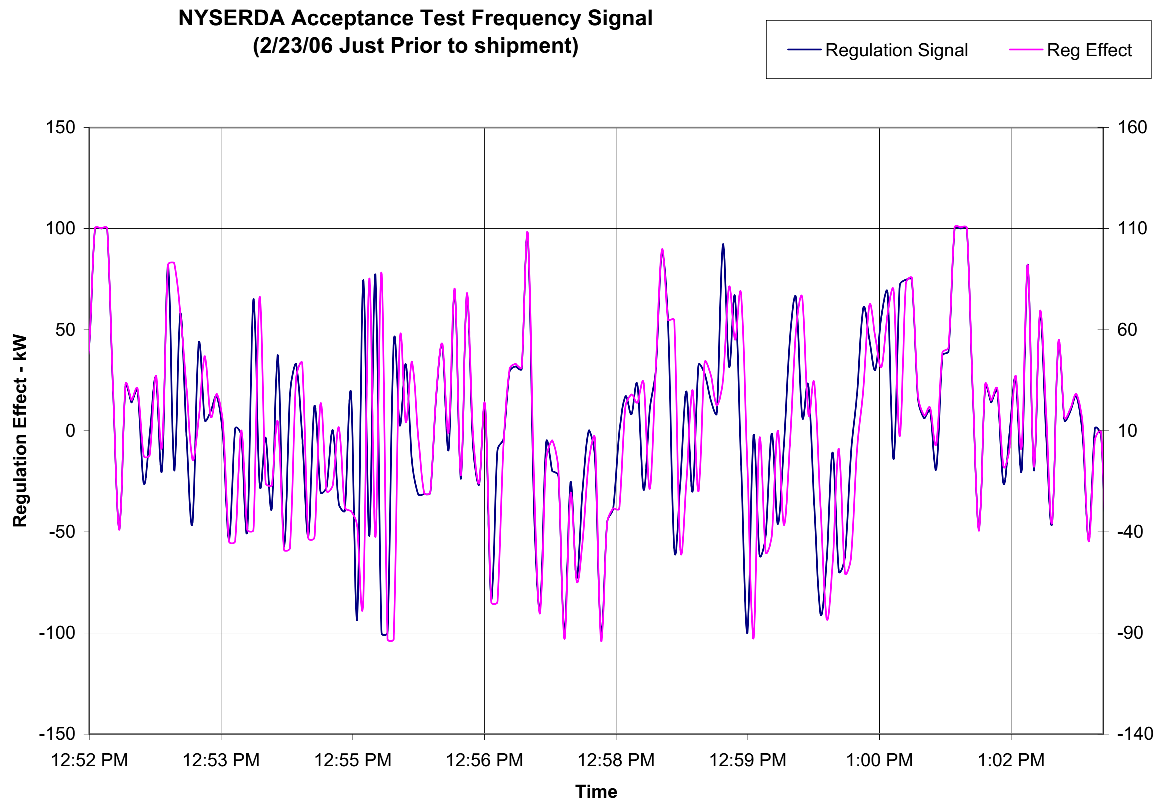
- Reactive Power Demonstration

- Normal Shutdown

Appendix B – Baseline Test Signal



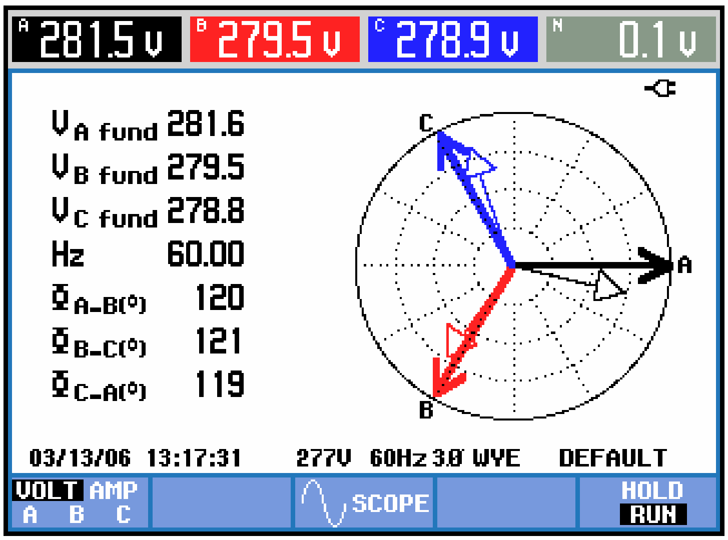
Appendix C – Frequency Test Signal



Appendix D – Reactive Power Tests

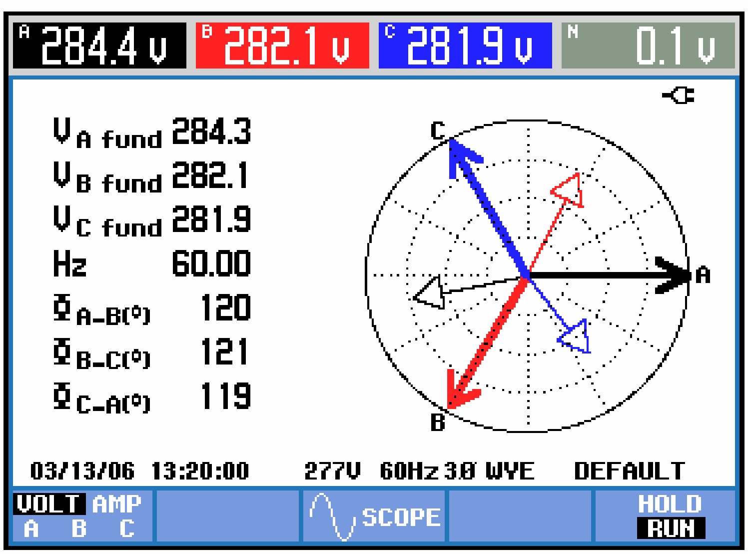
The following charts display the SEM output voltage phase angle compared to the phase of the grid. The first chart sows unity PF (Power Factor) where they are in phase. Subsequent charts show the phase angle as we charge and discharge the flywheel at various levels of real and reactive power. During field testing the capability of providing reactive power on the local building power factor will be demonstrated

Phasor diagram at 60KW Charge (absorbing)



Voltage and current in line, unity P.F

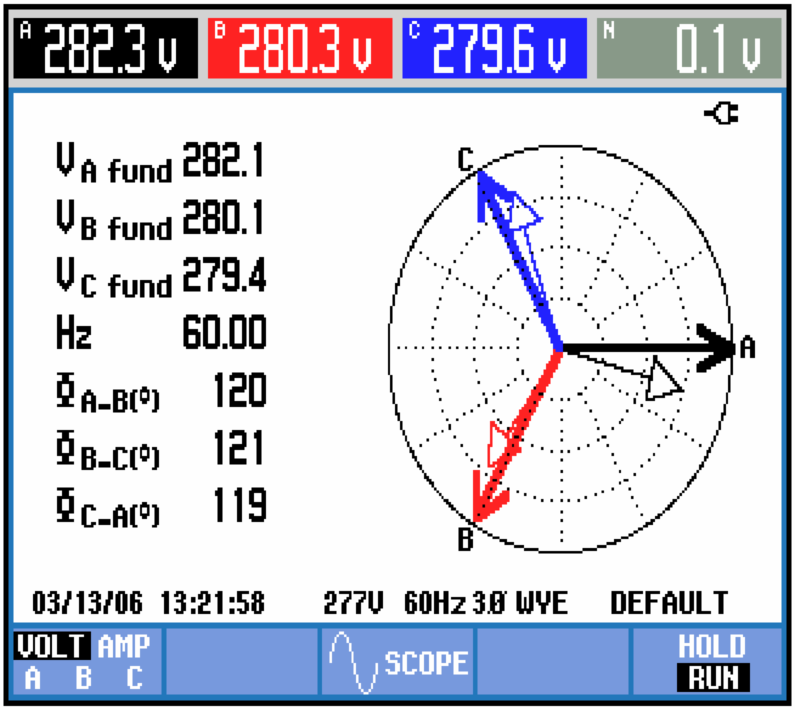
Phasor diagram at 40KW Discharge (Injecting)



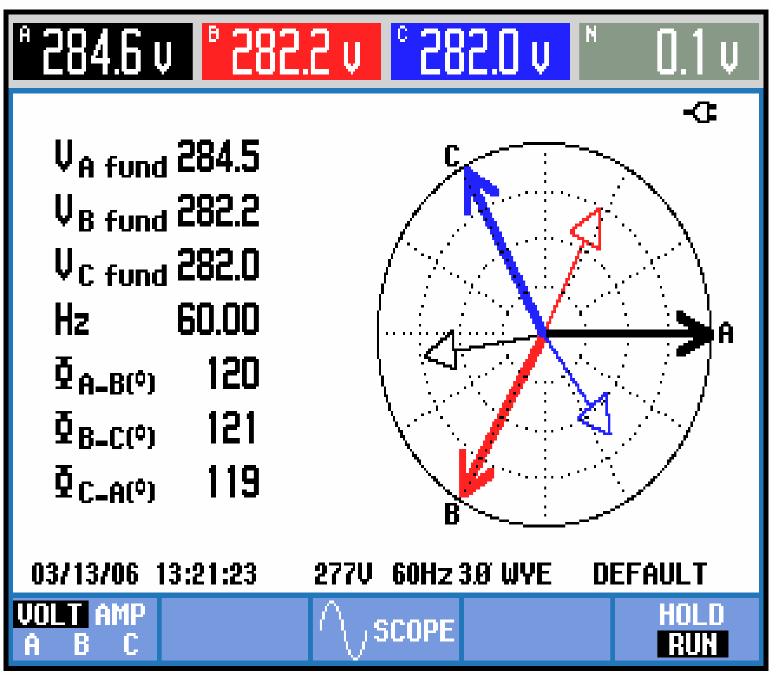
Voltage and current out of phase

Appendix D – Reactive Power Tests

Phasor diagram at 50KW



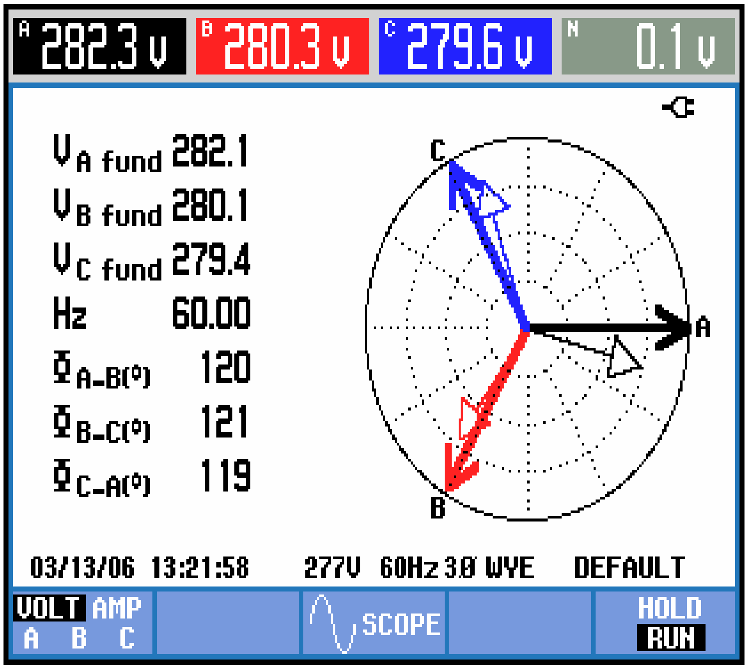
Charge, Voltage and current in line



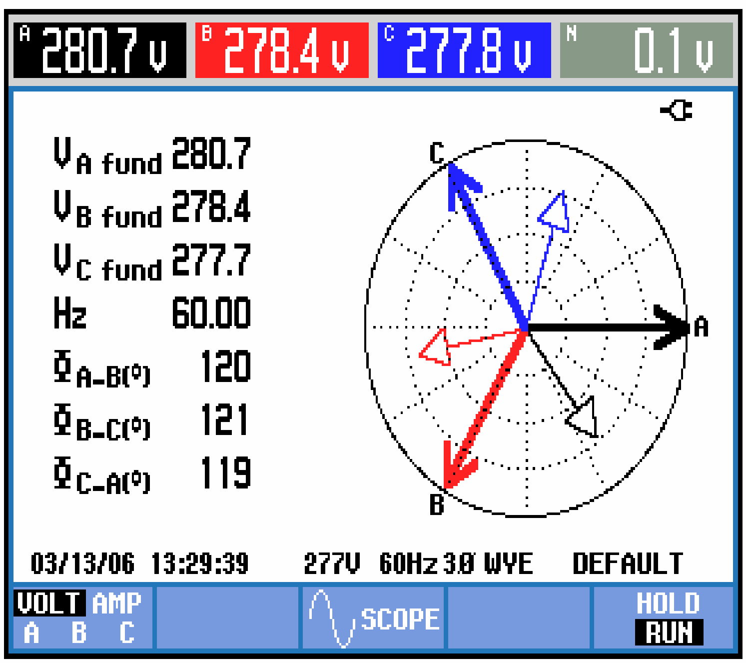
Discharge, voltage and current out of phase.

Appendix D – Reactive Power Tests

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



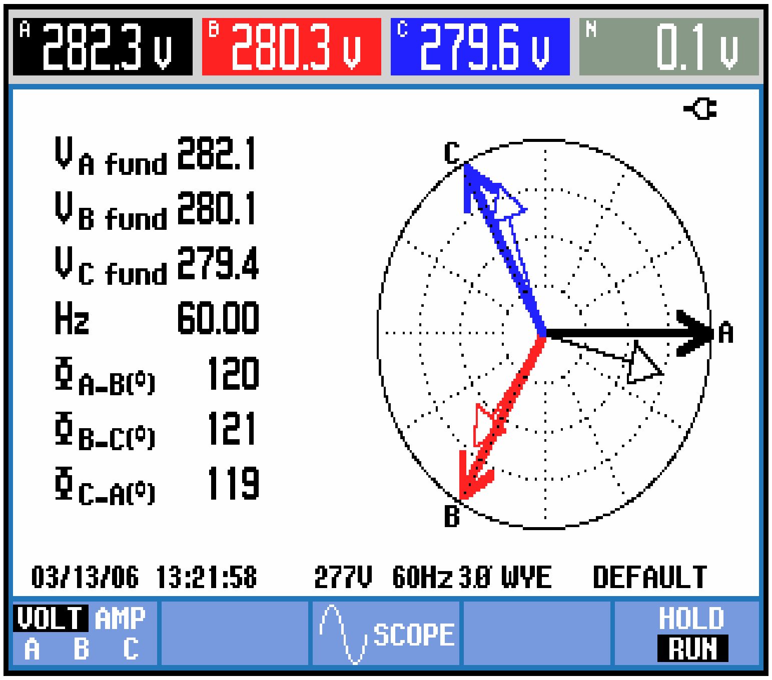
50KW



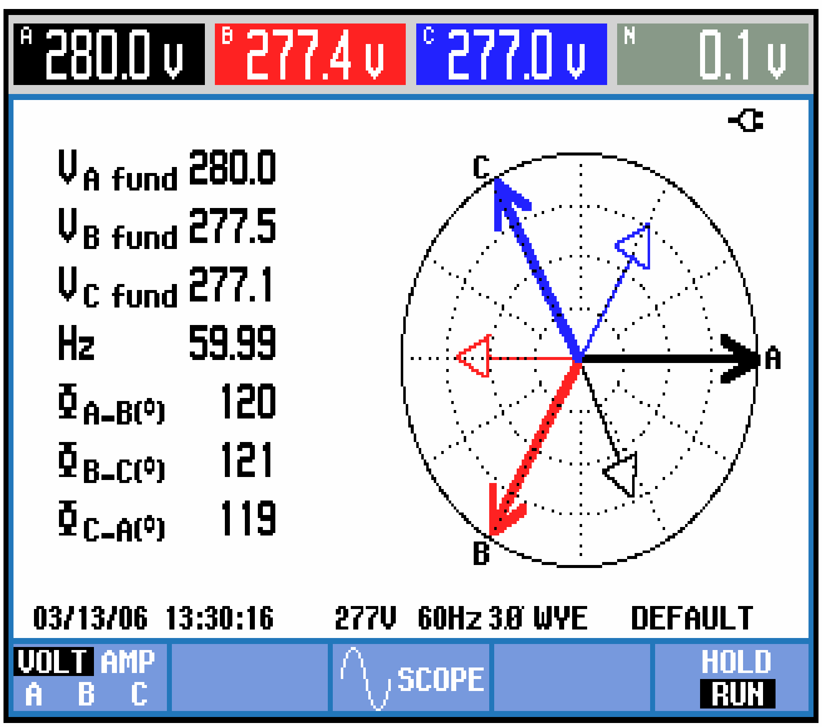
50KW charge 30KVAR, PF=0.66

Appendix D – Reactive Power Tests

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



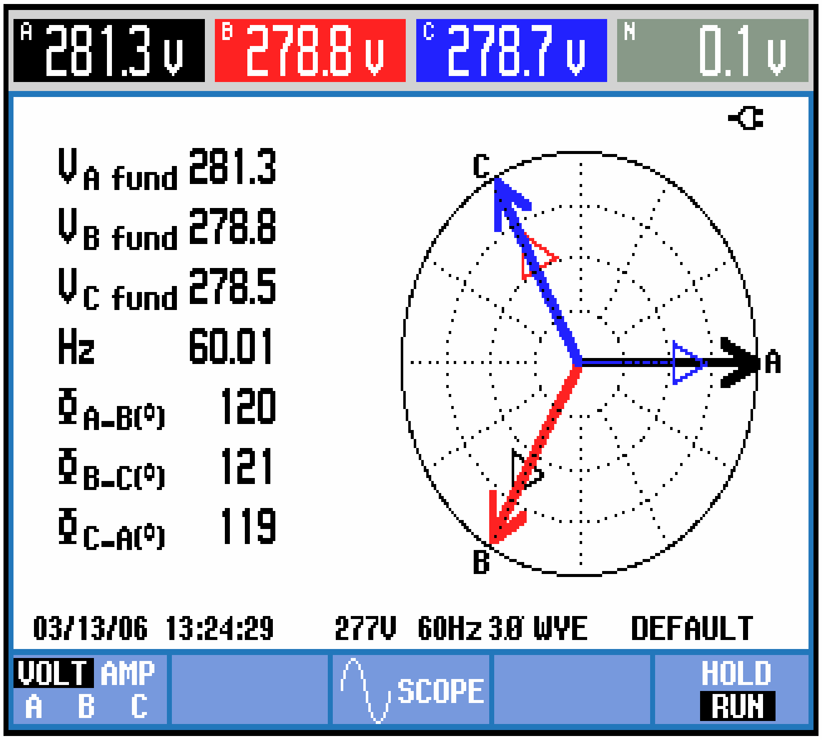
50 KW



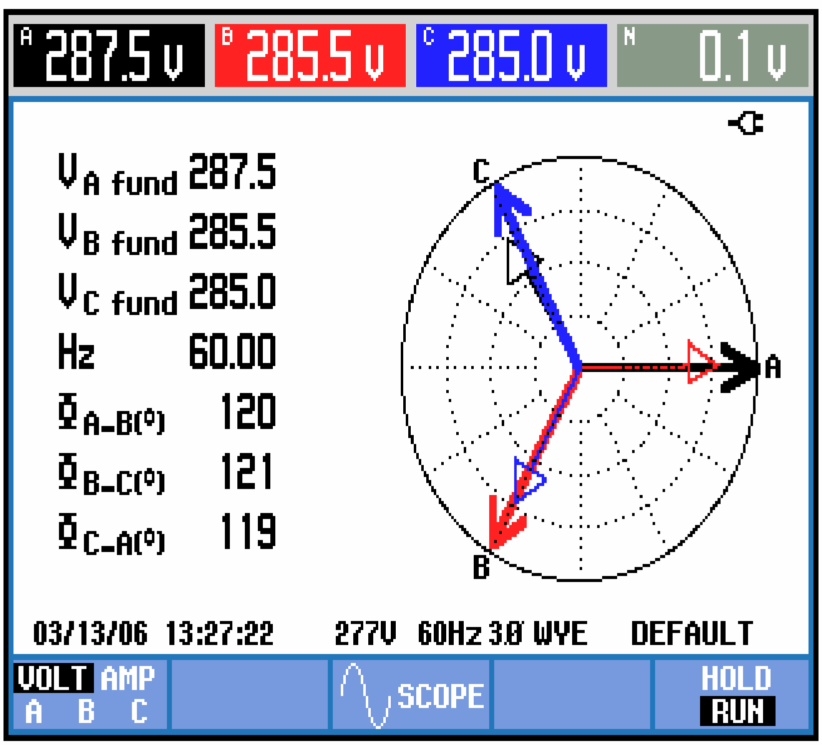
50KW charge, 50KVAR, PF= 0.472

Appendix D – Reactive Power Tests

Phasor diagram at 50KW discharge with VAR (Inductive, Capacitive)



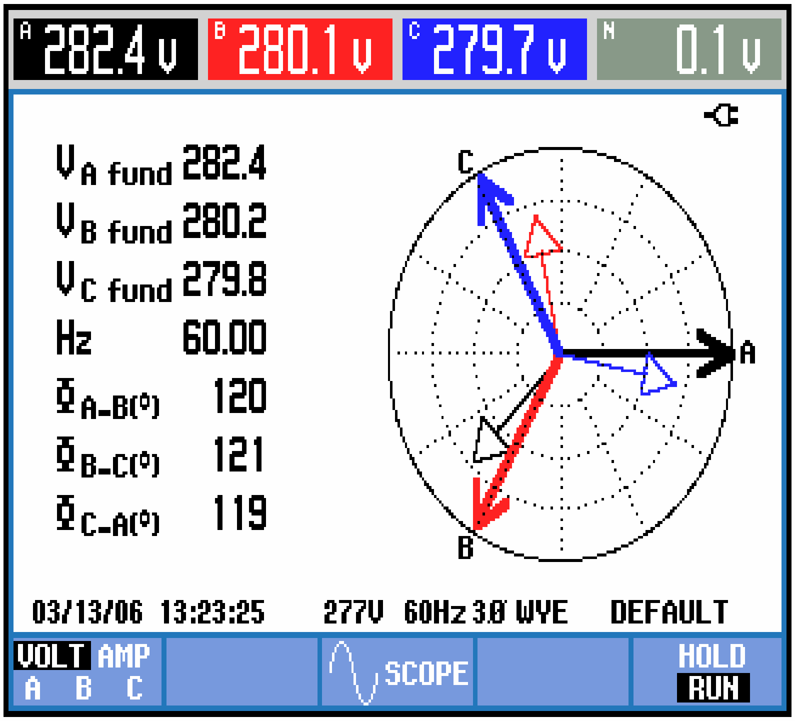
50KW discharge , 50KVAR, PF=-0.521 Inductive



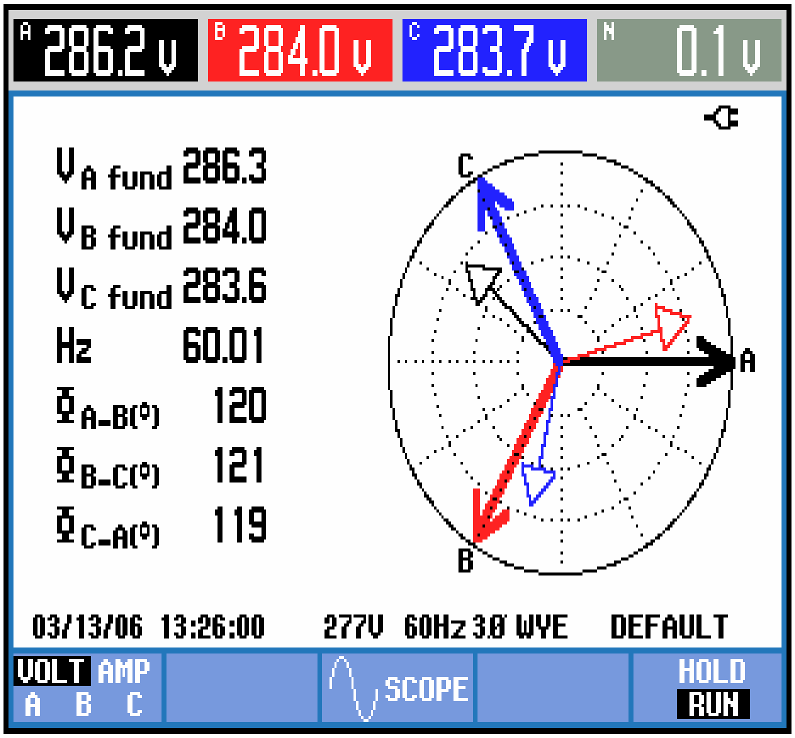
50KW Discharge, -50KVAR, pf= -0.534 Capacitive

Appendix D – Reactive Power Tests

Phasor diagram at 50KW discharge with VAR (Inductive, Capacitive)



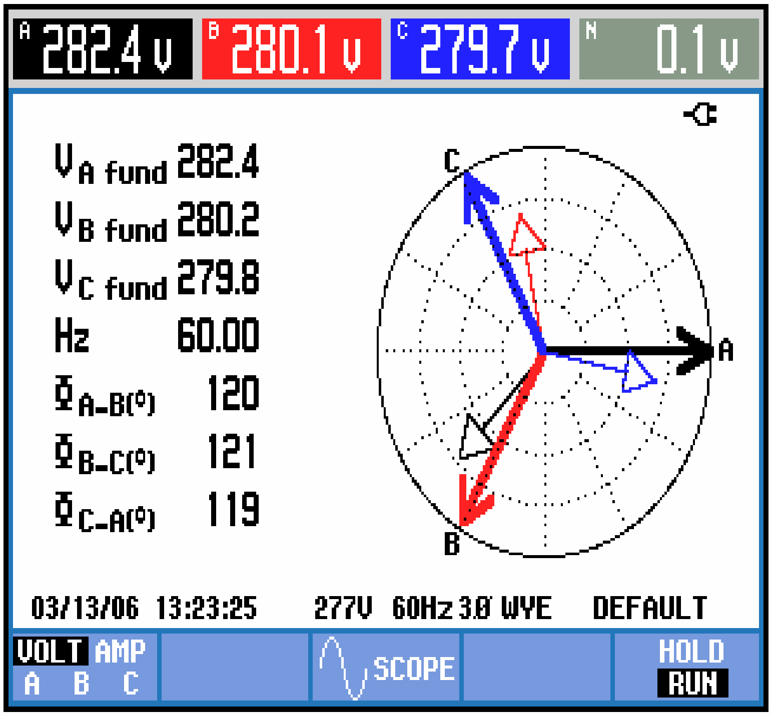
50KW discharge, 30KVAR pf=-.703 Inductive



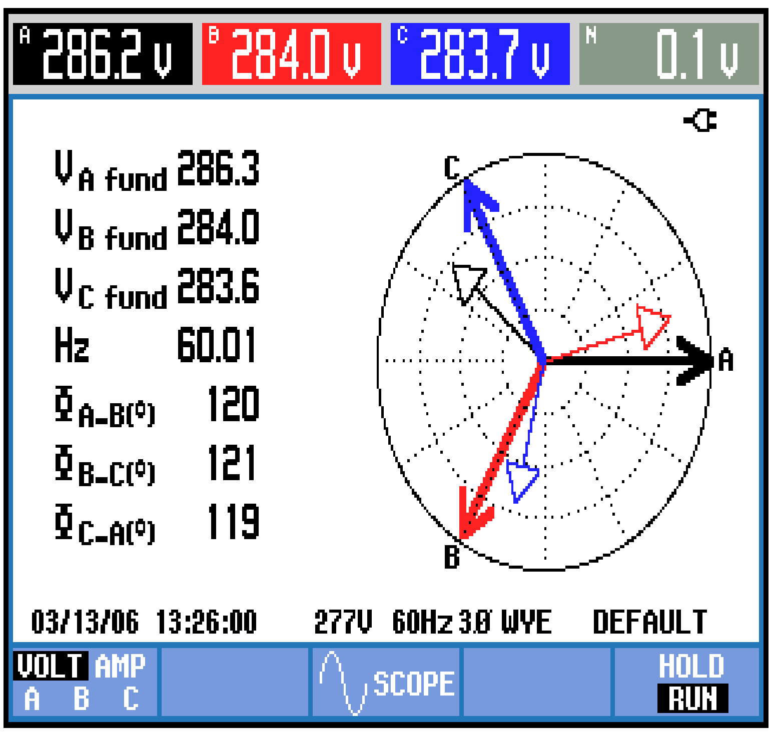
50KW discharge, -30KVAR, pf= -.742 Capacitive

Appendix D – Reactive Power Tests

Phasor diagram at 50KW discharge with VAR (Inductive, Capacitive)

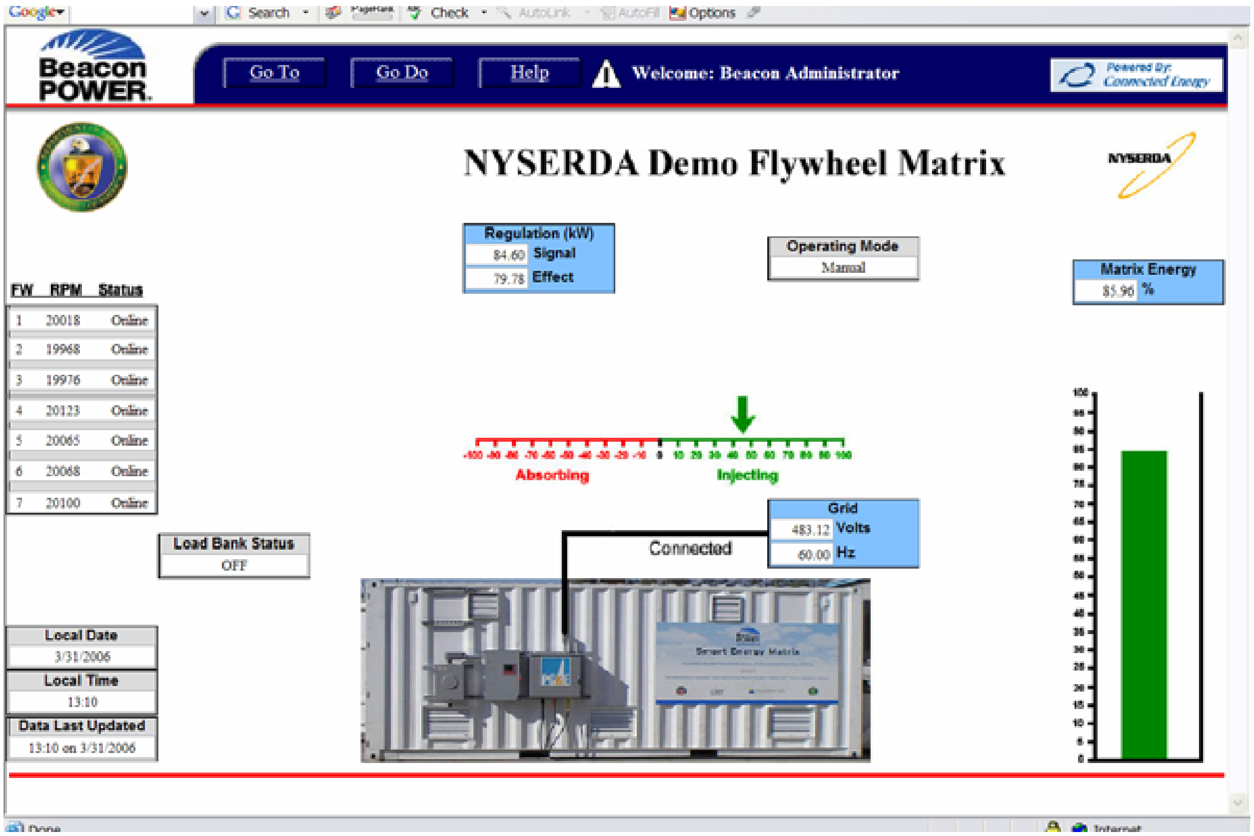


50KW discharge, 30KVAR pf=-.703 Inductive



50KW discharge, -30KVAR, pf= -.742 Capacitive

Appendix E – Connected Energy Webpage



Appendix 8.3
NYSERDA Field Trial Test Plan

Smart Energy Matrix Field Trial Test Program

For

A Beacon Power Flywheel Energy Storage System

Installed in the PCT facility in Amsterdam NY

Prepared by:

Jim Arseneaux, Beacon Power

Dave Lundell, Beacon Power

June 28, 2006

Amended per letter from Georgianne Peek of Sandia to Joe Sayer, dated March 6, 2007. See Copy in last page of this report.

Abstract

This document describes the field test plans for Beacon Power's Smart Energy Matrix (SEM).

The key functionality requirements include validating:

- Communications and Controls
- Calibration
- Performance Envelope
- Dynamic Response
- Reliability

The test plan will be performed by Beacon personnel remotely via the internet.

The six-month field trial testing will demonstrate the ability of the SEM to follow a frequency regulation signal received by a precision frequency meter at the test site which is measuring actual grid frequency.   Data will be gathered and analyzed by EnerNex Corporation for the United States Department of Energy. Overall performance and reliability will be monitored and evaluated. In addition, the ability of the SEM to deliver reactive power will be demonstrated

Contents

Overview

Initial functional tests have been completed at PCT.

The six-month field trial testing will demonstrate the ability of the SEM to follow a frequency regulation signal received by a precision frequency meter at the test site which is measuring actual grid frequency.   Data will be gathered and analyzed by EnerNex Corporation for the United States Department of Energy. Overall performance and reliability will be monitored and evaluated. In addition, the ability of the SEM to deliver reactive power will be demonstrated.

The contract shows 18 months of testing. It is believed all objectives can be demonstrated in a shorter time period. During the initial 6 month field trial test other concepts will be presented to better utilize the system for other purposes in addition to frequency regulation. *After 8 months of official testing agreement was reached with Sandia (Georgianne Peek) and NYSERDA (Joe Sayer) to suspend testing. It was determined that enough data was collected to evaluate system performance. It was also agreed that because this was demonstration hardware it was more beneficial to focus on the product hardware and ISO integration. The system was put in standby mode from march 6th,2007 until Mach 19th 2008. Not additional test were identified and the system was then decommissioned. This agreement is documented in a letter at the end of this amended report.*

Background

Beacon Power Corporation is working under a NYSERDA contract to demonstrate the viability of its flywheel-based Smart Energy Matrix (SEM) to provide grid frequency regulation at the utility transmission level.

The demonstration project includes the installation of a fully functional demonstrator SEM, a 100kW system in a 20' shipping container, capable of discharging 25kWh over 20 minutes. A commercial version is intended to be installed in a 40' container, and rated at 1MW/250kWh.

Intended Application

Effective frequency and voltage regulation are key elements in providing the stability and reliability of the nation's grid. Today, frequency regulation is primarily performed by constantly adjusting the output of generators that are tied back to the respective control area. As the need for regulation services is becoming more critical, there is growing concern about the availability and pricing of such services. The primary causes are:

- Older steam generators, the most common source of regulation services, are being decommissioned.
- Gas turbines operate at a higher cost.
- Hydroelectric capacity is unlikely to grow because of environmental concerns.
- The addition of wind resources to meet renewable mandates requires even more regulation services.

The 8/14/2003 blackout in the US and Canada brought this sharply into focus. One of the primary recommendations of the Blackout Report, published in its wake, was to mandate conformance with the reliability metrics that are voluntary today. All control areas (such as PJM or CAISO) have associated metrics (CPS1 and CPS2) to keep the Area Control Error (ACE) within limits. With expected legislation, significant penalties are expected for CPS1 and CPS2 deviations.

See www.beaconpower.com for additional details including a video overview of the principles of frequency regulation.

PCT System Installation

The SEM was installed on March, 2006. It is self-contained in a 20' shipping container, comprising seven flywheel modules, monitoring and control equipment, a chiller, and a load bank.

The SEM has been interconnected to the National Grid network via a 480V level in the PCT facility. Step-up transformers are used to connect to the 21kV line.

The field trial performance analysis will rely on the SEM's power monitor and onboard equipment as well as data from the Dranetz power monitoring system run by Sandia/EnerNex Corp.

Figure 1: SEM Installation at PCT

.

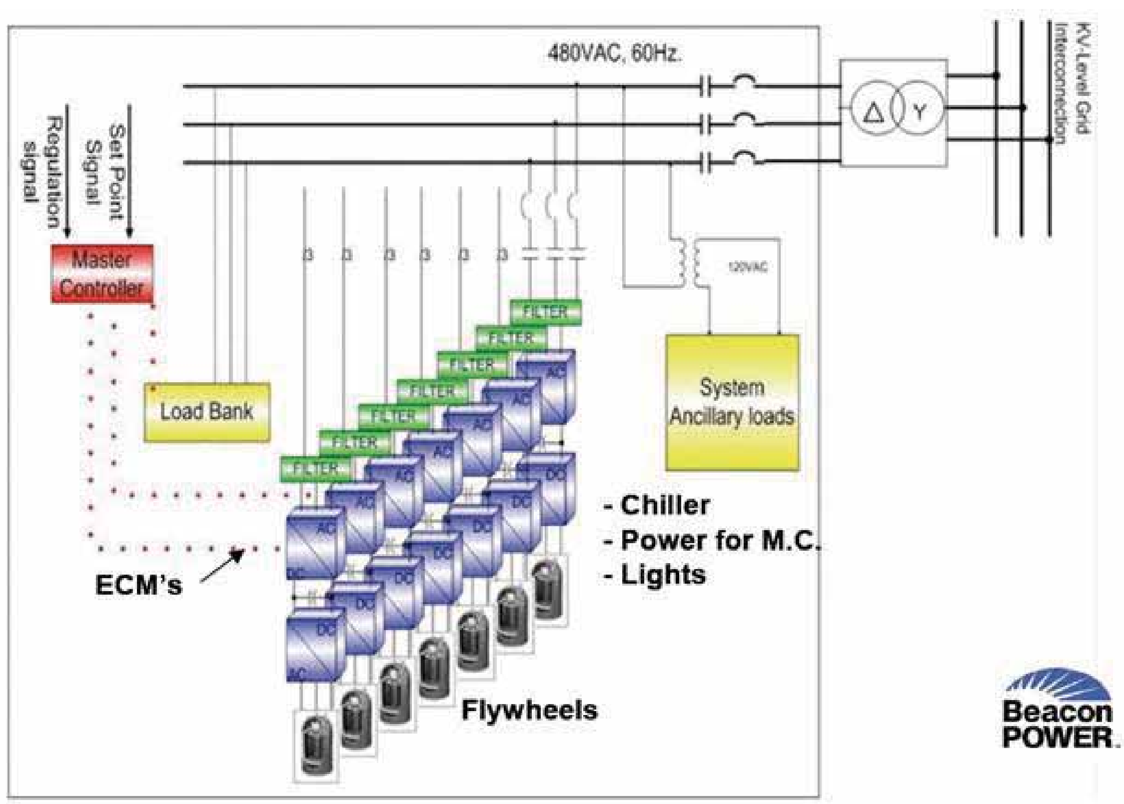

DANGER
HIGH
VOLTAGE

SEM Layout

Figure 3 shows the internal schematic of the system. The system includes seven flywheels, power electronics, switchgear, a load bank and all ancillary equipment to keep the system running. Once the container is closed it has only two connection points.

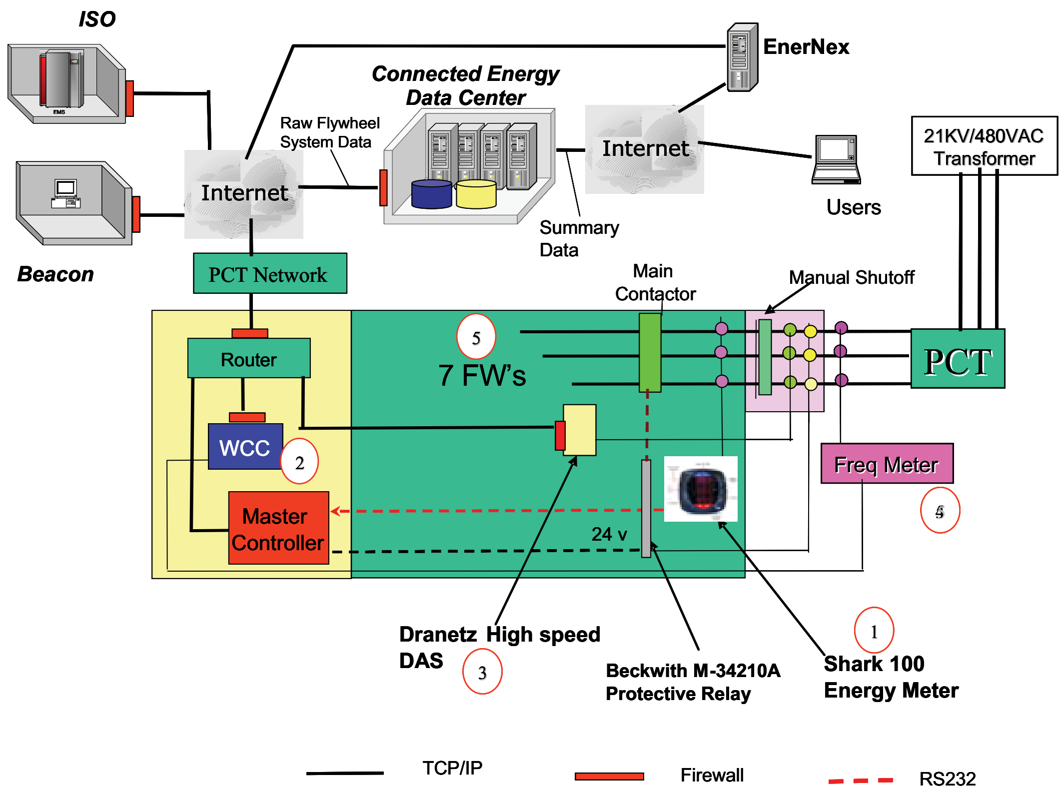
1. The internet connection which is used to receive a signal to inject or absorb power. Operational data is also sent out across this connection.
2. A three-phase 480 VAC connection to the step-up transformer.

The primary function of the system is to respond to a regulation signal from the ISO to perform frequency regulation by injecting or absorbing power based on a signal. Other functions may be evaluated later.



Data Systems

The figure below shows the data systems available in the SEM. It also shows team members that can access the system via the internet. All system controls are inputted across a TCIP/IP network connection via a Graphical User Interface (GUI) operated by PCT or Beacon Power personnel. The table on the following page defines the type of data, storage location and access for each of the five reference numbers on the figure below.



Ref #	Data Type	Data Source	Storage Location
password access	System Performance Data - Regulation Effect - Net power - Set Point (e.g. 5kW)	Shark 100 Energy Meter plus master controller. Connected just inboard of the manual shutoff.	Master Controller and Connected Energy Data Center
password access	Regulation Signal	Frequency Meter	Master Controller and Connected Energy Data Center
password access	System Performance Data DOE Independent Measurement	Dranetz Dual Node	Dranetz on site and EnerNex Corporation
Frequency Meter	Grid Frequency	PCT DAS	Master Controller and Connected Energy Data Center
Beacon data only	Detailed Flywheel and Secondary System Data	Flywheel and system instrumentation	Master Controller and Connected Energy Data Center

Figure 4: SEM Data Systems

Preliminary Test Phase

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1. Functional Test

General

Beacon Power will perform all testing per the test plan and report results to NYSERDA and DOE.

All testing will be coordinated with Eric Gunther of EnerNex Corp. Prior to testing, all data systems will be time-coordinated.

GUI & Control Validation – Completed

Features of the Graphic User Interface are shown below. Each function shall be tested prior to initiating

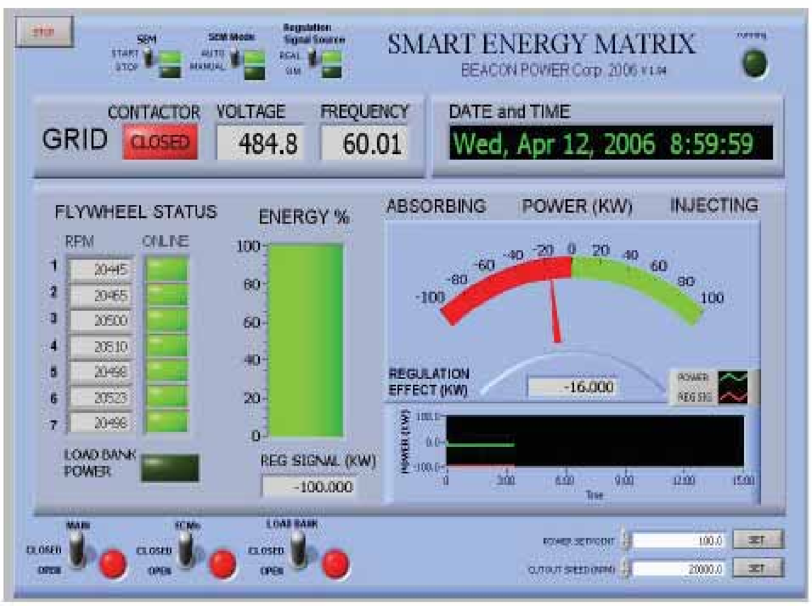

Figure 5: Local User Terminal GUI

Initial Cycling – – Completed

The initial cycling is intended to confirm control over the system and provide a brief check on full operability prior to more detailed work. To do this, charge the SEM at the 100kW rate to a full energy capacity (~22,000rpm). Then command a 100kW discharge of the system to 0% available energy capacity (~12,000rpm).

Calibration – Completed

The accuracy of the utility parameters must be verified by comparing readings from the Dranetz DAS System, the Shark Meter, and the Beacon GUI on the local user terminal. These calibrations must account for the predetermined set-point.

2. *Safety Checkout – Completed*

Factory Safety

- Over-speed check. Set system to 100kW charge cycle. Shut off user interface. Restart user interface after thirty minutes. Check that all flywheels are below their max speed limit.

- Fault check rim temp. With all flywheels in frequency regulation mode, change the rim temperature limit to a value below its current temperature reading. The unit should fault within one minute. A text message should be sent to Beacon personnel within fifteen minutes.

Validate E-Stop Triggers

Validate that the system can be shut down from the various disconnects and emergency shutdown controls.

3. *System Protection – Completed*

Basic Anti-Islanding Function

The purpose of this testing is to assure the system disconnects within two seconds after grid loss.

3.1.1 Idling – flywheels at nominal operating speed without charging or discharging the system.
3.1.2 Charging – increasing the flywheel speeds with a 100kW charge.
3.1.3 Discharging – reducing the flywheel speeds with a 100kW discharge.
3.1.4 ISO Mode – SEM is responding to the simulated ISO control signal.

It must be confirmed that the SEM has returned to a normal operating mode after each of these tests.

4. *Energy Characterization*

The maximum charge and discharge rates and periods will be tested in 33kW increments, ranging from charging 100kW to discharging 100kW. Plots of power vs. time will be completed.

5. *Dynamic Response*

This test will look at the current and voltage waveforms as the SEM transitions between charge to discharge and back at various ratings. It must be verified that that the transition occurs smoothly without transmitting significant distortions to the grid.

The SEM will broadcast a trigger signal on the same subnet that the Dranetz is on, indicating when a reversal of current occurs. The Dranetz will then be allowed to collect waveform data to determine how long it takes for the system to re-stabilize. This data will be collected during the 6 month field trial.

6. *Pretest Power Quality Survey : Completed*

Prior to the field testing of the SEM, the Dranetz power quality monitoring system and associated current and voltage sensors were installed at the service entrance of the PCT plant. This system was connected to the Internet and the data was recorded and analyzed by EnerNex Corp. Prior to the field test period, the Dranetz was relocated to measure the power quality at the output/input connection of the SEM.

7. *Reactive Power Injection Demonstration:*

The purpose of this demonstration is to show the ability to provide reactive power on command in order to improve the power factor at an industrial plant. At a designated time during the field trial, Beacon will install power measurement instrumentation at the service entrance of the PCT facility. This will consist of a power meter (Yokogawa WT1600) and associated current and voltage sensors. The meter will provide real-time readings of real and reactive power, power factor, and phasor displays. Plant data will be observed and stored immediately prior to the demonstration.

By remote command the SEM will supply reactive power in increasing increments opposite to the reactive power in the plant. The SEM will then reduce the reactive power injection to zero. Real and reactive power, power factor and phasor data will be observed and stored at appropriate intervals during the demonstration.

Note: Initial checkout of this function was demonstrated during the development phase. During the 6 month field test a formal test will be conducted and documented for the final report.

Field Trial Testing *(Contract calls for 18 months – Final agreement was 8 months per letter at the end of this report)*

1. ***Test Objective:*** The purpose of the six month trial is to:
    - Provide confidence in the system durability. Although this is a scaled demonstration unit the same technology is planned for full scale product. Data will be collected to assess the reliability of the flywheels as well as the ability of the overall system to perform its intended function.
    - Obtain data on the system's ability to follow various signals that could be used by the ISO to perform frequency regulation. This data will be used in conjunction with ISO input, to determine how a product flywheel system would be operated and what the economic benefits would be.
2. ***Test Log:*** A log will be kept indicating when a test is started, what the initial parameters are and changes that are made via the system GUI (Graphical User Interface) or any physical changes are made to the system configuration. This would include components replaced or repaired as well as setup changes. Beacon will have ability to monitor the system, but must record any changes and communicate changes to other team members. This would include changes to operating limits and/or software updates.

3. ***Test Procedure:***
    a. Start system per user manual
    b. Select parameters for test case to be run (see table on next pg) and select Pmax on Connected Energy Web Page.
    c. Set Power Set Point with the Operator's GUI per table below.
    d. Set Cutout Speed with the Operator's GUI
    e. Set Regulation Signal to Real with the Operator's GUI.
    f. Log start time of test and estimate completion time.

4. *Initial Test Cases:* The following are the initial test cases planned. Data from each test case will be summarized by Beacon. Based on results, future test cases may be modified or added to.

Test Case #	Max Demo Regulation P_{max} kW	Power Set point-kW	Cutout Speed	Source of signal Real or Playback*	Duration	Purpose
1	60	20	17,000	Real	1 week	Baseline Data
1B	60	20	17,000	Playback	1 week	Baseline Data
2A	80	20	17,000	Playback	1 week	System scale impact
2B	100	20	17,000	Playback	1 week	System Scale impact
3A	60	20	15,000	Playback	1 week	Cutout speed impact
3B	80	20	15,000	Playback	1 week	Cutout speed impact
3C	100	20	15,000	Playback	1 week	Cutout speed impact
4A	60	15	15,000	Playback	1 week	Set Point Impact
4B	80	15	15,000	Playback	1 week	Set Point Impact
4C	100	15	15,000	Playback	1 week	Set Point Impact
5	TBD	TBD	TBD	Playback	1 week	Run with optimization from above.
6	TBD	TBD	TBD	Real	1 week	Case 5 with new frequency data. No time correction.
7	TBD	TBD	TBD	Playback	1 week	Case 6 with time correction.

* Playback involves repeating historical signal with time corrections. IE – regulate relative to the target frequency vs straight 60hz. If all goes without delay the above cases will take 7 weeks. Based on review of the data from

these cases Beacon will recommend settings for extended periods of testing to complete the remaining durability test to add up to 6 months.

5. Data Summaries:

***Beacon Summary*:**

For each case above data will be collected on all DAS systems. The following will be summarized using the 4 second data from the Connected Energy Data Center.

- Time system is offline
- Time system is at less than planned capacity (flywheels offline)
- Time system is offline due to grid disturbances / Beckwith trips
- Time system is unable to follow the signal (system empty)
- Average deviation from the signal – Average % difference (Signal – Regulation Effect)/Signal. Calculated every 4 seconds system is on line. Averaged over the test cycle.
- Net Energy injected. - kWh
- Net Energy absorbed - kWh

EnerNex Summary

Reference EnerNex contract "Data Management for California Energy Commission / DOE Energy Storage Initiative Projects" Data required to complete analysis per this contract will be a combination of data sent to EnerNex via an FTP site daily and data collected from the on site Dranetz.

6. Monitoring

The system will be started and all test conditions will be set per the test plan. Beacon will get a text message whenever there is a system fault from the Connected Energy Data Center. Beacon will be responsible for reviewing the fault, taking appropriate action to keep the system running safely and reporting any actions taken to the team members.

7. Abnormal Events

All abnormal events that occur during the field trial test period will be recorded in log sheet. These events will be evaluated as external or internal to the SEM. In the case of an external event, the source of the event will be determined and evaluated for preventative action. In the case of an internal event, such as a component malfunction or failure, the cause will be determined. A corrective action plan will be implemented as required.

Acronyms

ACE	Area Control Error
NYISO	New York Independent System Operator
CPS	Control Performance Standard
DAS	Data Acquisition System
DEG	Distributed Energy Generator
DER	Distributed Energy Resource
DOE	Department of Energy
DUT	Device Under Test
ECM	Energy Conversion Module
IEEE	Institute of Electrical and Electronic Engineers
EPS	Electric Power System
GUI	Graphic User Interface
ISO	Independent System Operator
KVAR	Kilovolt-ampere-reactive
MGTF	Modular Generation Test Facility
NREL	National Renewable Energy Laboratory
PCT	Power Composites Technologies
RPM	Revolutions Per Minute
RTO	Regional Transmission Organizations
SEM	Smart Energy Matrix
SNL	Sandia National Laboratories
SOC	State of Charge
PIER	Public Interest Energy Research
UL	Underwriter's Laboratory
WCC	Web Communications Controller
TCP/IP	Transmission Control Protocol /Internet Protocol
CPS1	Control Performance Standard 1
CPS2	Control performance Standard 2

Amendment to Smart Energy Matrix Field Trial Test Program

Sandia National Laboratories

Operated for the U.S. Department of Energy by

Sandia Corporation

Georgianne H. Peek, PE, PMP
Principle Member of Technical Staff

P.O. Box 5800
Albuquerque, NM 87185-1108

Phone: (505) 844-9855
Fax: (505) 844-0968
Internet: ghpeek@sandia.gov

March 6, 2007

Joe Sayer
NYSERDA
17 Columbia Circle
Albany, NY 12203-6399

Joe,

This letter is to formally inform you that sufficient data has been collected by EnerNex Corp., for the NYSERDA/ DOE Joint Energy Storage Initiative, to begin a comprehensive analysis of system performance of the 100 kW, 15 min prototype flywheel frequency regulation demonstration by Beacon Power.

As we agreed at the March 1, 2007 progress meeting, Beacon should continue by pursuing communications with the NY ISO to determine their needs, requirements, how they implement area control and what the steps are to enter the frequency regulation market in NY. The Beacon Flywheel Energy Storage System, at the Amsterdam site, should be put in a standby mode, and be ready to address specific items that come out the meetings with the NY ISO.

Sincerely,

Georgianne H. Peek, PE, PMP
Sandia National Laboratories
Electrical Energy Storage and Distributed Energy Resources
P.O. Box 5800
Albuquerque, NM 87185-1108
ghpeek@sandia.gov
505-844-9855

Appendix 8.4
Quotes from NYISO and NYSERDA

News Release

Beacon Power Announces Successful Outcome of Flywheel Frequency Regulation Testing in New York

New York Independent System Operator (ISO) Says Beacon's Flywheel Technology is Viable for Use in the State's Power Grid

WILMINGTON, Mass.--(BUSINESS WIRE)--March 22, 2007--Beacon Power Corporation (NASDAQ: BCON), a company that designs and develops advanced products and services to support more stable, reliable and efficient electricity grid operation, today announced that the New York State Energy Research and Development Authority (NYSERDA) and the U.S. Department of Energy (DOE) have confirmed the successful outcome of field trial testing of Beacon's scale-power flywheel frequency regulation system in New York. In addition, the New York ISO, which operates the power grid, determined that Beacon's technology is viable for connection to the grid.

These milestones follow the January announcement that Beacon's first flywheel frequency regulation demonstration system had received certification from the California ISO after successfully completing its field trial in that state.

"After evaluating the test results and discussing Beacon's performance with representatives of the California ISO, we find the Beacon flywheel technology to be acceptable and viable for use in the New York ISO grid," said Michael Calimano, vice president of operations, New York ISO. "We are currently determining how the service would be integrated into our tariff structure, and we look forward to working with Beacon Power to implement this important new technology."

"NYSERDA is pleased with the successful outcome of Beacon's frequency regulation field trial that was performed in New York, in cooperation with our partners at the U.S. Department of Energy," said Peter R. Smith, president and CEO of NYSERDA. "We look forward to continuing our role in facilitating the commercial deployment of this innovative technology within New York's electricity grid."

Beacon's New York-based flywheel system field trial reached this milestone after the U.S. DOE (through Sandia National Laboratories, which co-monitored the demonstration with NYSERDA) concluded that the unit's performance had been successfully demonstrated and that additional testing was not required. The flywheel system will remain in place in Amsterdam, New York, to respond to any additional control methodology demonstration that may be requested by the New York ISO.

"This is another significant achievement for Beacon Power and a major step towards our goal of becoming the nation's first independent provider of frequency regulation services using our flywheel technology," said Bill Capp. "With both Smart Energy Matrix system field trials successfully concluded we can now focus on commercial implementation of this technology in our targeted grid operating regions."

Beacon's New York-based flywheel demonstration system was installed in March 2006 and began its formal field trial in June. The goal was to determine its ability to provide fast-response frequency regulation, as well as another ancillary service called reactive power. In comparison to California, where Beacon's system was controlled by a signal sent every four seconds by the grid operator, the New York system consistently responded to frequency variations it sensed through its direct grid connection. In addition, in cooperation with the New York ISO and a major international utility, the system also successfully demonstrated its ability to provide reactive power, a secondary service that the grid requires to maintain stability.

Beacon is now evaluating potential operation in California, New York, New England and the Mid-Atlantic regions for its commercial-sized frequency regulation plants, the first of which Beacon plans to build in 2008.

About NYSERDA

The New York State Energy Research and Development Authority (NYSERDA) was established by law in l975 as a public benefits corporation. NYSERDA provides energy-related technical and financial packaging assistance to businesses and institutions to promote energy efficiency and economic development, as well as providing energy research and development programs that promote safe and economical energy production efficiency technologies in New York State. NYSERDA also analyzes the effect of New York's energy, regulatory and environmental policies on the State's business, institutional, and residential energy consumers.

About the New York ISO

The New York Independent System Operator (NYISO) is a federally regulated, 501(c) 3 nonprofit corporation established in 1999 to facilitate the restructuring of New York's electric industry. The NYISO operates the state's high-voltage electric transmission system and administers the state's wholesale energy markets. The NYISO's market volume was $8.6 billion in 2006. For more information, visit www.nyiso.com.

About Beacon Power

Beacon Power Corporation designs and develops advanced products and services to support stable, reliable and efficient electricity grid operation. The Company's primary business strategy is to commercialize its patented flywheel energy storage technology to perform frequency regulation services on the grid. Beacon's Smart Energy Matrix, now being demonstrated on a scale-power level in two states, is a prototype for a non-polluting, megawatt-level, utility-grade flywheel-based solution that would provide sustainable frequency regulation services. Beacon is a publicly traded company with its research, development and manufacturing facility in the U.S. For more information, visit www.beaconpower.com.

Safe Harbor Statements under the Private Securities Litigation Reform Act of 1995: Material contained in this press release may include statements that are not historical facts and are considered "forward-looking" within the meaning of the Private Securities Litigation Reform Act of 1995. These forward-looking statements reflect Beacon Power Corporation's current views about future events and financial performances. These forward-looking statements are identified by the use of terms and phrases such as "believe," "expect," "plan," "anticipate," and similar expressions identifying forward-looking statements. Investors should not rely on forward-looking statements because they are subject to a variety of risks, uncertainties, and other factors that could cause actual results to differ materially from Beacon Power Corporation's expectation. These factors include: a short operating history; a history of losses and anticipated continued losses from operations; a need to raise additional capital combined with a questionable ability to do so; conditions in target markets; no experience manufacturing any product or supplying frequency regulation services on a commercial basis; limited commercial contracts for sales to date; the dependence of sales on the achievement of product development and commercialization milestones, including design modifications that may be needed following a recent malfunction that occurred while testing a prototype flywheel; the uncertainty of the political and economic climate, and the different electrical grid characteristics and requirements of any foreign countries into which Beacon hopes to sell or operate, including the uncertainty of enforcing contracts, the different market structures, and the potential substantial fluctuation in currency exchange rates in those countries; significant technological challenges to successfully complete product development; dependence on third-party suppliers; intense competition from companies with greater financial resources, especially from companies that are already in the frequency regulation market; possible government regulation that would impede the ability to market products or services or affect market size; the complexity and other challenges of arranging project finance and resources for one or more frequency regulation power plants; possible product liability claims and the negative publicity which could result; any failure to protect intellectual property; retaining key executives and the possible need in the future to hire and retain key executives; the recent volatility in the stock price of companies operating in the same sector. These factors are elaborated upon and other factors may be disclosed from time to time in Beacon Power Corporation's filings with the Securities and Exchange Commission. Beacon Power Corporation expressly does not undertake any duty to update forward-looking statements.

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Appendix 8.5
Reactive Power Injection Report

Smart Energy Matrix Field
Trial Test Program

Reactive Power Injection Demonstration

Rev. 02, February 7, 2008

Site: PCT facility in Amsterdam, NY

Test equipment: FLUKE 434 Power Quality Analyzer SN DM8910051

Test performed by: DL and RB Beacon Power on Dec. 20, 2006.

Test objective:

- Demonstrate the ability of the Smart Energy Matrix to improve the Power Factor of an industrial facility.
- Demonstrate the ability of the Smart Energy Matrix to supply reactive power in the industrial environment.

Summary:

The test clearly demonstrates the ability of the Smart Energy Matrix to improve Power Factor of an industrial facility and to supply reactive power of any character (inductive and capacitive) in the industrial environment.

The Smart Energy Matrix responded remotely and was able to change the PF of the facility in the range from 0.8 to 0.98 and inject up to 54 kVAr of inductive and up to 57 kVAr of capacitive reactive power. This represents approximately 50% of the Smart Energy Matrix capabilities.

The improvement of the Power Factor has the ability to reduce the reactive current drawn by the industrial facility, financially benefiting both the facility owner and the utility.

Single Line Diagram

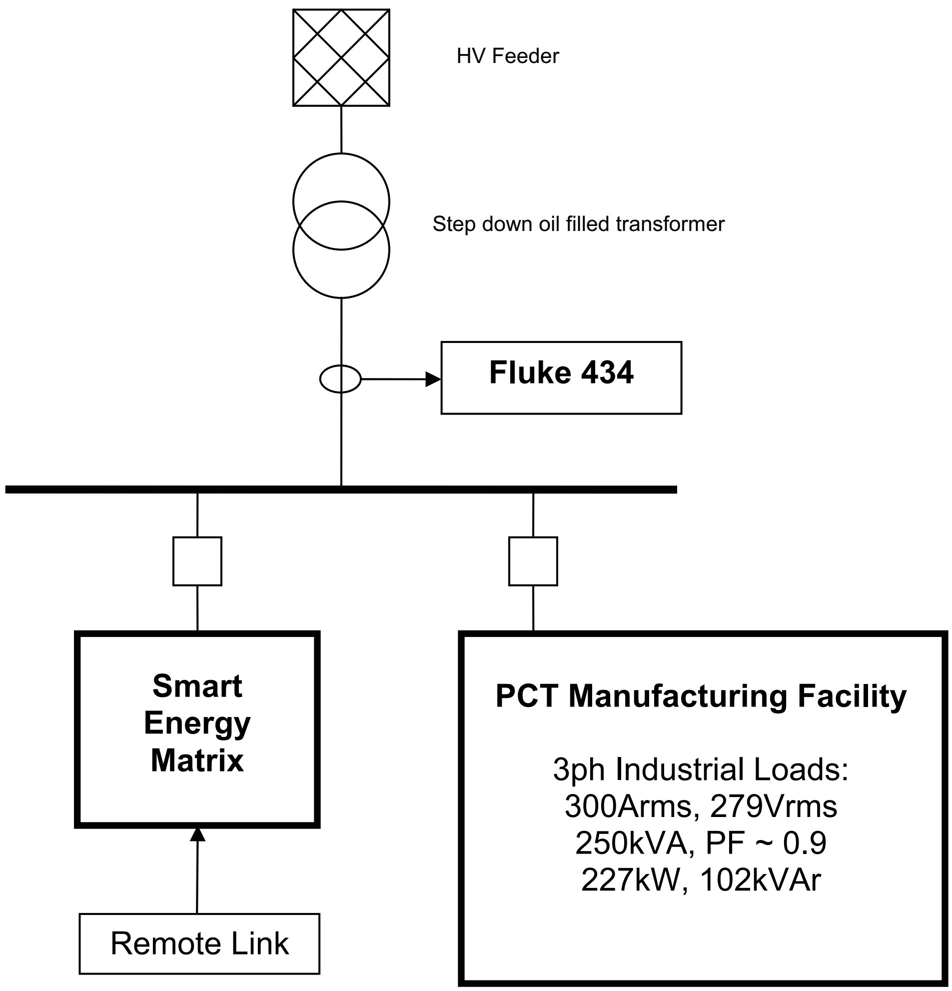

Fig. 1 Single line diagram of the test.

Explanation of Test Data Figures 2 - 7:

Two tests were performed and data was recorded on the power analyzer.
Figures 2 – 4 represent the data from the Power Factor test. Figures 5 – 7 represent the data from the Reactive Power test.
The top three traces are the individual phases. The bottom trace is the total. The numerical values are displayed at the top of the frame.
During the tests, the SEM was controlled from Beacon Power in Wilmington MA. using an Internet connection.
The tests were performed at a time of day when heavy machinery was not switching on and off in order to avoid noise in the data during the tests.
For both tests the baseline data was recorded with the SEM in standby mode then the SEM was commanded to step the capacitive reactive power up and down then step the inductive reactive power up and down. This was repeated until there was sufficient stored data.
Figures 2 and 5 show the complete traces of the Power Factor and Reactive Power tests (respectively). The cursor is positioned on the facility baseline level with the SEM in standby mode.
Figures 3, 4, 6 and 7 zoom in on the areas of the test where the reactive power was being injected by the SEM. The reported value from the cursor position is displayed in the top right corner of the frame.

Ability of the Smart Energy Matrix to improve Power Factor of an industrial facility

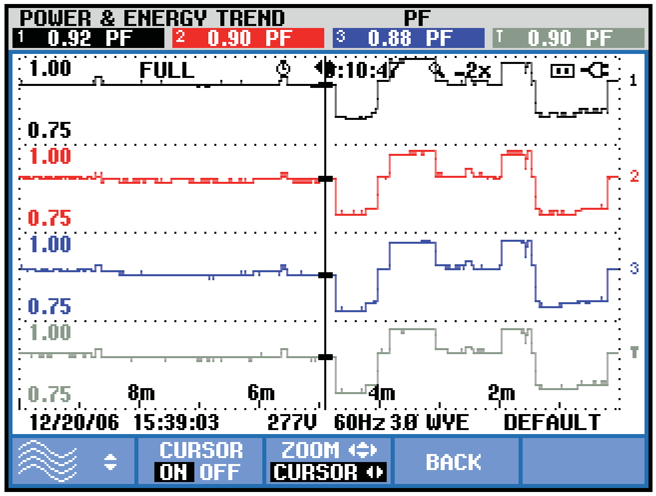

Fig. 2 Power Factor (PF) before test = 0.9.

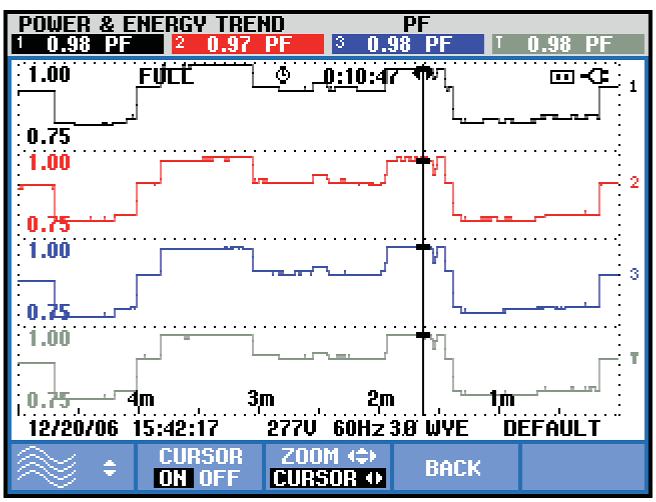

Fig. 3 Smart Energy Matrix supplies capacitive power. PF improved from 0.9 to 0.98

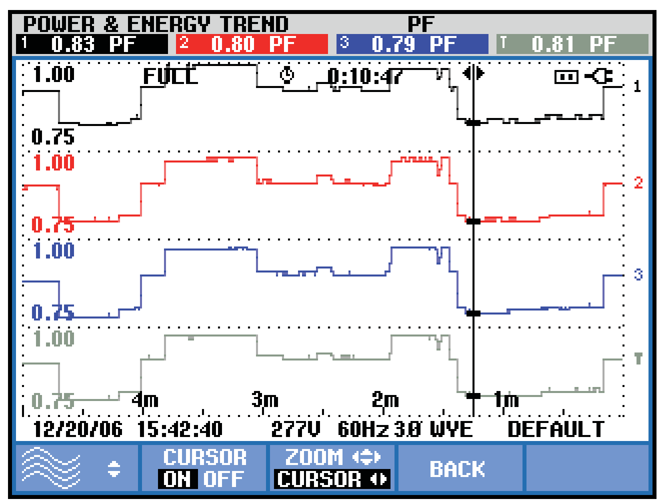

Fig. 4 Smart Energy Matrix supplies inductive power. PF of the industrial facility changed from 0.9 to 0.8

Ability of the Smart Energy Matrix to supply reactive power

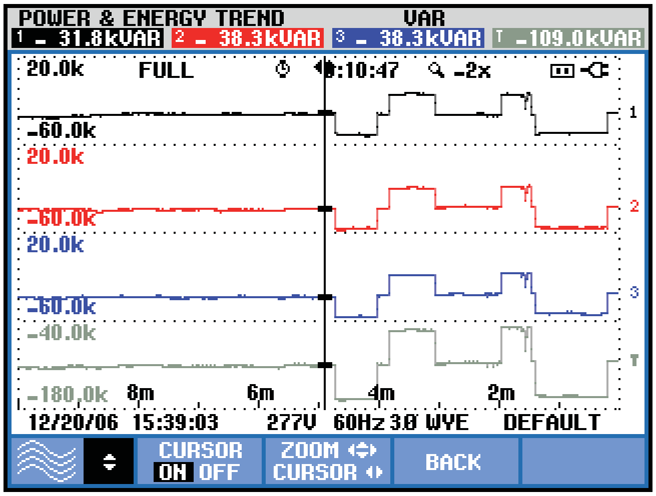

Fig. 5 Total reactive power before test = 109kVAr.

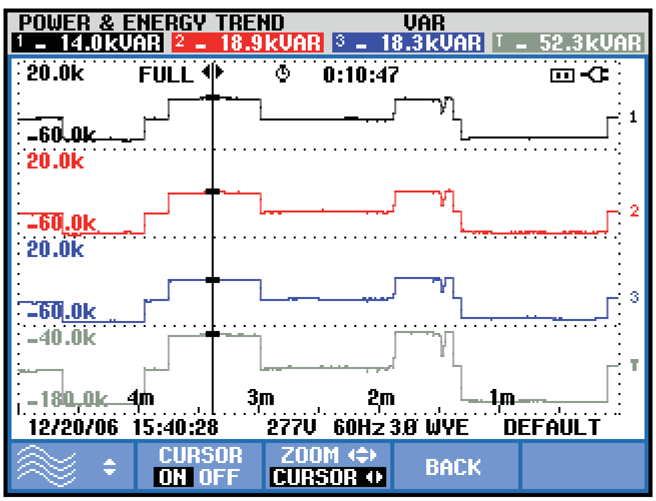

Fig. 6 Smart Energy Matrix supplies capacitive reactive power. The reactive load of the industrial facility changed from 109kVAr to 52kVAr.

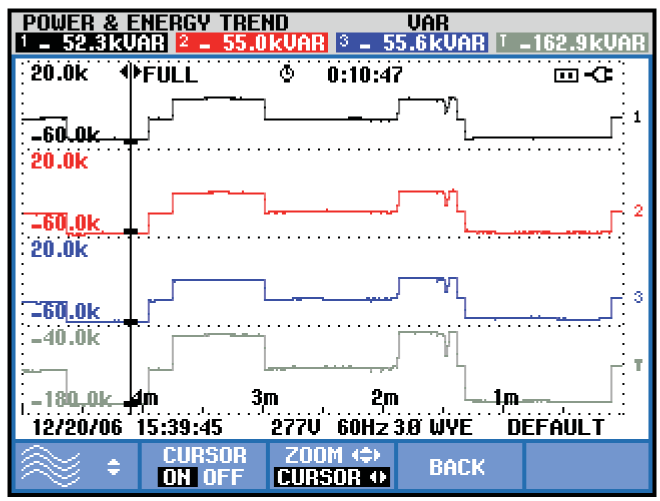

Fig. 7 Smart Energy Matrix supplies inductive reactive power. The reactive load of the industrial facility changed from 109kVAr to 163kVAr.

KEMA

Appendix 8.6

Emissions Analysis Report

Emissions Comparison for a 20 MW Flywheel-based Frequency Regulation Power Plant

Beacon Power Corporation

KEMA Project: BPCC.0003.001

May 18, 2007

Final Report with Updated Data

Emissions Comparison for a 20 MW Flywheel-based Frequency Regulation Power Plant

Final Report with Updated Data

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KEMA-Inc. Project: BPCC.0003.001 Beacon Flywheel Project

Under Beacon Power Contract Number: 12952 of October 13, 2006

Beacon Power Contract Funded by the US DOE Through Sandia National Laboratories

May 18, 2007

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EXECUTIVE SUMMARY

KEMA Inc. was commissioned by Beacon Power to evaluate various performance aspects of the Beacon Power 20 MW flywheel-based frequency regulation power plant, including its emissions characteristics. To support the emissions evaluation, a detailed model was created to compare the emissions of CO_2, SO_2 and NO_x for a Beacon Power flywheel plant versus three types of commercially available power generation technologies used in the market to perform frequency regulation ancillary services.

The comparison of generation technologies included a typical coal-fired power plant, natural gas combustion turbine, and pumped storage hydro system. Emissions from the coal and natural gas-fired generation technologies result directly from their operation because they burn fossil fuels. In contrast, emissions for the flywheel and pumped hydro energy storage systems occur indirectly because they use some electricity from the grid to compensate for energy losses during operation. The emissions characteristics for these losses are based on the emission characteristics for the specific ISO area where the flywheel and pumped storage system are being used.

The mix of power generation technologies and average system heat rates for fossil-based power generation systems varies across regions in the United States. To obtain a regionally adjusted emissions comparison, system data specific to three Independent System Operator (ISO) regions were examined: PJM (Mid-Atlantic), California ISO (CAISO), and ISO New England (ISO NE). Data for each of these ISOs was extracted from the Department of Energy (DOE) Energy Information Administration (EIA) and Environmental Protection Agency (EPA) eGRID databases. Model calculations assumed typical heat rate and efficiency data for each type of generation.

For coal and natural gas-fired generation, KEMA's research found that frequency regulation results in increased fuel consumption on the order of 0.5 to 1.5%.[1] This finding is supported from estimates made by a U.S. DOE National Lab, information obtained from the ISOs, and from a European study that evaluated electricity producers to determine whether power plants providing frequency regulation had an increase in fuel consumption and maintenance requirements. This effect was reflected in the model.

Based on the above data, model analysis showed that flywheel-based frequency regulation can be expected to produce significantly less CO_2 for all three regions and all of the generation technologies, as well as less NO_x and SO_2 emissions for all technologies in the CAISO region. The flywheel system resulted in slightly higher indirect emissions of NO_x and SO_2 in PJM and ISO NE for gas-fired

1 A 0.7% increase in fuel consumption due to frequency regulation was assumed in the model for this study.

generation. This is because PJM and ISO NE's generation mix includes coal-fired plants, and make-up electricity used by the flywheel and hydro systems reflects higher NO_x and SO_2 emissions from electricity generated in those areas. This effect was greatest in PJM because it has proportionally more coal-fired plants than ISO NE.

When the flywheel system was compared against "peaker" plants for the same fossil generation technologies, the emissions advantages of the flywheel system were even greater. Model results for each of the ISO territories are summarized in Table 1, Table 2, and Table 3 on the following pages.

Table 1: Emissions Comparison for PJM

Flywheel Emission Savings Over 20-year Life: PJM					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	149,246	149,246	149,246	149,246	149,246
Alternate Gen.	308,845	616,509	194,918	224,439	202,497
Savings (Flywheel)	159,599	467,263	45,672	75,193	53,252
Percent Savings	52%	76%	23%	34%	26%
SO2					
Flywheel	962	962	962	962	962
Alternate Gen.	2,088	5,307	0	0	1,305
Savings (Flywheel)	1,127	4,345	-962	-962	343
Percent Savings	54%	82%	n/a	n/a	26%
NOx					
Flywheel	259	259	259	259	259
Alternate Gen.	543	1,381	105	154	351
Savings (Flywheel)	284	1,122	-154	-105	92
Percent Savings	52%	81%	-148%	-68%	26%

Table 2: Emissions Comparisons for CAISO

Flywheel Emission Savings Over 20-year Life: CA-ISO					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	91,079	91,079	91,079	91,079	91,079
Alternate Gen.	322,009	608,354	194,534	223,997	123,577
Savings (Flywheel)	230,930	517,274	103,455	132,917	32,498
Percent Savings	72%	85%	53%	59%	26%
SO2					
Flywheel	63	63	63	63	63
Alternate Gen.	1,103	2,803	0	0	85
Savings (Flywheel)	1,041	2,741	-63	-63	23
Percent Savings	94%	98%	n/a	n/a	27%
NOx					
Flywheel	64	64	64	64	64
Alternate Gen.	499	1,269	80	118	87
Savings (Flywheel)	435	1,205	16	54	23
Percent Savings	87%	95%	20%	46%	26%

Table 3: Emissions Comparisons for ISO-NE

Flywheel Emission Savings Over 20-year Life: ISO-NE					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	106,697	106,697	106,697	106,697	106,697
Alternate Gen.	304,759	608,354	197,359	227,249	144,766
Savings (Flywheel)	198,062	501,657	90,662	120,552	38,070
Percent Savings	65%	82%	46%	53%	26%
SO2					
Flywheel	270	270	270	270	270
Alternate Gen.	1,300	3,303	0	0	367
Savings (Flywheel)	1,030	3,033	-270	-270	96
Percent Savings	79%	92%	n/a	n/a	26%
NOx					
Flywheel	115	115	115	115	115
Alternate Gen.	416	990	58	85	157
Savings (Flywheel)	301	875	-58	-31	41
Percent Savings	72%	88%	-101%	-36%	26%

The emissions estimates under the scenarios listed above show highly favorable comparisons for the flywheel across all generation technologies.

The remaining sections of the report provide the assumptions that were used in the modeling as well as further insights and analysis.

A full summary of the emission comparisons is provided in Section 4.3. The final data was based on the operation of a "typical" power plant for each of the categories. Analysis using known heat rates for a specific generating plant performing regulation would improve the accuracy of model comparisons relative to that specific plant.

1. Introduction

Beacon has requested that KEMA perform a two-phased technology evaluation of a 20 MW flywheel technology contrasting flywheel-based frequency regulation with conventional fossil, hydro and lead acid solutions with respect to:

Phase I: Environmental impact evaluation of the flywheel system with other commercially utilized frequency regulation technologies, bidding into the ancillary services market.

Phase II: Benefits of fast response to grid frequency regulation management, updated life-cycle environmental impacts and cost-performance analysis of the flywheel.

This report addresses Phase I, evaluating the environmental impact of the flywheel, compared to other existing commercially available technologies for frequency regulation as an ancillary service.

2. Scope of Work and Work plan

2.1 Technologies

KEMA evaluated the following technologies for frequency regulation at three locations. One in the CAISO service area, one in the PJM service area and one in the ISO New England service area:

a) Beacon Flywheel (Nominal power at 20MW plant)

b) Conventional coal-fired fossil generating plants (Base Load and Peaker plants)

c) Conventional gas-fired fossil generating plants (Base Load and Peaker plants)

d) Pumped Hydro Storage

2.2 Environmental Impact Evaluation

The Beacon flywheel is evaluated against other generation for the purpose of frequency regulation based on emissions and includes the following:

a) Impact of the operation of the storage system to the environment - Quantified in tons of CO_2, NO_x, and SO_2.

b) Assumptions are provided to Beacon and collectively accepted before the analysis commences.

c) As part of the assignment a proprietary environmental evaluation tool was developed by KEMA.

d) The deliverable for the Phase I task is this report on the possible emissions savings.

3. Assumptions and Approach

3.1 General Assumptions Emissions Calculations

For coal and natural gas, a simplified approach was used to characterize whether plant efficiencies at altering loads have a large impact on actual emissions output. For coal and natural gas, emissions can vary depending on other factors. For coal, it can depend on the type of coal and firing conditions, while natural gas has efficiency variances around not only loading but also temperature factors. Hence, for the analysis, the following simplified assumptions were used:

(i) Comparisons of the natural gas and coal plant emissions were made against units that did not have emission reduction equipment in the case of NO_2 and SO_2.

(ii) For coal and natural gas base loaded plants, cycles were conducted around a 95% capacity factor with up and down ramping of +/- 5% of capacity. Cycling can be adjusted to occur around another factor by adjusting the Heat Rate factors for each of the charging and discharging inputs per the worksheet heat rate vs. capacity output table.

(iii) ISO related "System-wide" emission outputs were used in calculating the emissions from the flywheel and hydro pumped storage options associated with the losses. This data was taken from EPA eGRID [1] and DOE Energy Information Administration (EIA) [2] databases. System-wide ISO emissions do take emission control technology into account.

(iv) Coal emission factors are typically calculated based on loads of 80% or greater. Although the emissions generated at a given heat rate or efficiency are influenced by additional factors related to fuel type, the actual plant output has a more significant impact on the overall emissions, which allows the use of the simple calculation.

(v) Because the data was taken for one cycle and extrapolated over an entire year for the base load configurations, the focus of the model is on operations during that single cycle.

(vi) For coal and natural gas-fired generation, KEMA's research found that frequency regulation results in increased fuel consumption on the order of 0.5 to 1.5%. For this study 0.7% is used as the increased fuel consumption. This finding is supported from estimates made by a U.S. DOE National Lab, information obtained from ISOs, and from a European study [9, 10] that evaluated electricity producers to determine whether power plants providing frequency regulation had an increase in fuel consumption and maintenance requirements. This effect was reflected in the model.

3.2 Flywheel Charging and Discharging Cycles

For frequency regulation, the first general assumptions that were used were the number of cycles that occurred for each day. A cycle was defined as 15 minute ramp up or charging period, a 15 minute ramp down or discharging period, and 30 minutes of maintaining steady state or normal operations. For a complete day, 24 cycles were examined. The model uses a build-up approach that focuses on a single cycle, then extrapolates that data into a single day, a single year, and finally to a 20-year lifetime. Partial charges and discharge cycles were not considered. The flywheel was modeled as a system and emissions where calculated for all equipment and operations included in the entire system.

3.3 Flywheel Operation

For the flywheel to operate in frequency regulation mode, four separate modes of operation were taken into account. These include: ramp-up (charging), ramp down (discharging), steady state period where the voltage level is being maintained in the flywheel, and an accommodation for the percentage of time when the flywheel system is unavailable for frequency regulation because it has run out of energy. KEMA utilized Beacon data for this percentage. In the scale power test unit in California, Beacon determined the flywheel was available 98.3% of the time for frequency regulation. Hence, a factor of 1.7% was used to account for the percent of time that the unit was unavailable. The emissions are created during these operating scenarios by the flywheel using power from the grid to make up for the estimated 10% load losses on ramp up and ramp down, 1% energy required to maintain the flywheel, and the remaining unavailability utilization factor.

These idling losses (1%) of the flywheel can be absorbed from the grid or they can be compensated with renewable energy resources (solar or wind plant). In these calculations all flywheel losses are compensated by the generation mix of the specific ISO. Emissions rates used in these calculations use standard area fossil emission factors and "system" average heat rates and reflect the generation mix of the ISO region.

It was estimated that the flywheel system plant is able to provide only regulation during the availability period (assumed 98.3%) and that the overall charge - discharge efficiency of the flywheel is assumed at 80% (10% for ramp-up and 10% for ramp-down).

3.4 Coal-fired Plant Operation

The coal-fired plant emission data is calculated under two scenarios:

a) The first scenario is a base-load operation. Under this scenario, the coal plant is deemed to be a large power plant (400MW), base-loaded, and participating in a steady energy market. Hence, as the plant is considered to be already on-line, the emissions calculations above normal operations only occur when the plant is asked to increase its output (ramp-up) or decrease its output (ramp-down).

Summarizing:

i. A large power plant was used (400 MW) to represent a base-loaded coal plant that would be supplying wholesale energy to the market.

ii. Plant size was selected in order to allow a plant that could supply 20 MW around its rated 95 % capacity.

iii. Heat rates were used from a "general" coal plant without emissions reduction equipment [5]. General estimates of heat rate fluctuations off the 100% operation were obtained through an estimated heat rate curve.

iv. A cycle was determined by a ramp-up, increasing output to the grid, and ramp-down decreasing output of the power plant.

b) A second operating scenario is in "peaker" operation. Under this scenario, the emissions of the coal plant are estimated in a "peaker" operating mode. In a "peaker" operating mode the plant is only operating to participate in the frequency regulation market. In this case, the ramp up and ramp down emissions are calculated, as well as idling emissions, where the emissions for the output while idling are compared against the same output that would have been produced by a plant running at full rated capacity. Data for typical emission rates were taken from the EPA eGRID [1] and DOE EIA [2] databases on ISO emission factors. It is assumed that these plants operate only for a limited time during the day and year.

Summarizing:

i. The power plant operates for a limited number of hours per day (typically 6-12 hours per day). In this calculation 8 hours was used.

ii. A size of 75 MW plant size was assumed in order to allow power plant output to swing from + 20 MW to – 20 MW around an idling situation.

iii. Model assumes plant is in idling model of operation to respond to frequency regulation, emissions for idling condition (supplying power to market) is counted towards emission. Amount of emissions is calculated by comparing the emissions of the idling power plant to that of a power plant providing the equivalent amount of output (MW) while operating at its full rated capacity. The emission of the plant operated at full capacity is used as a plant would otherwise be supplying that power and output to the grid (100% base loaded operation).

iv. Ramp up and ramp down cycles are measured against output swings around the idling capacity of 50%.

v. For peaking plants, a decrease in output of plant has a more dominant effect on the results than the rising heat rate. Ramp-down cycles act as an offset to the ramp-up cycle.

vi. Fuel content for CO_2, SO_2, and NO_x were based on coal power generation data from 2004 EPA eGRID [1], and the 2000 DOE EIA [2] databases for the specific regions examined. (PJM, ISO NE, CA ISO).

3.5 Natural Gas Fired Combustion Turbines

Like the coal-fired power plants, the natural gas turbines are operated in the same modes of operation – Base-load and "Peaker" operation as discussed in Section 3.4. Heat rate data from a typical natural gas fired plant was utilized for the study. As the emission factors for the natural gas plants are lower than for coal, estimated emissions were correspondingly less than those produced by coal-fired plants. Lifetime emissions savings for a flywheel regulation plant replacing a base-load natural gas-fired plant were calculated to be 23-53% for CO_2, depending on the ISO region.

The analysis showed the flywheel to have greater emission than the natural gas plant for SO_2 and NO_x. These differences are accounted from the fact the flywheel creates its emissions indirectly from an average of all generation sources on the system. These system averages were taken from EPA eGRID [1] and DOE EIA [2] databases. This is the main driver to the natural gas power plant producing less NO_x and SO_2 emissions versus the flywheel-based system.

KEMA believes that a significant amount of frequency regulation is conducted with natural gas combustion turbines. Operation of the base loaded and peaker power plants were similar to the coal units. The main differences between the two technologies are in the size of the efficiency fluctuations and a higher minimum load level used for gas generation compared to coal. The analysis only varied heat rate based on partial loading. Natural gas turbine efficiencies are also typically subject to variations such as temperature. However, for this analysis, only efficiency fluctuations were included.

3.6 Hydro Pump Storage

Pump-storage scenarios were similar to the flywheel scenario insofar as like the flywheel regulation, hydro regulation does not produce emissions directly. The indirect emissions that were calculated were based on the inefficiencies of the system and the extra energy that is required to make up for the losses. The losses associated with ramping up and ramping down are larger than that of the flywheel since the efficiency of a hydro pump storage facility is lower. Thus the overall emissions for hydro pump storage are greater than those for the flywheel. It was estimated that a pump hydro plant is able to provide regulation 100% of time. The overall charge - discharge efficiency of the hydro system was estimated at 70%.

3.7 Assumptions on ISO Generation Mix

The mix of power generation technologies and average system heat rates for fossil-based power generation systems varies across regions in the United States. To obtain a regionally adjusted emissions comparison, system data specific to three Independent System Operator (ISO) regions were examined: PJM (Mid-Atlantic), California ISO (CAISO), and ISO New England (ISO NE). The year 2004 data in the EPA eGRID [1] and year 2000 DOE EIA [2] databases were used to assume the different generation mixes in the different ISOs investigated. Model calculations assumed typical heat rate and efficiency data for each type of generation.

The flywheel emissions were compared to the emissions of the generators that are currently actively bidding into the frequency regulation ancillary services market. These are mainly natural gas, coal and oil power plants. A summary of the year 2004 generation mixes for each of the ISO territories used in the analysis is shown below in Table 4.

Table 4: Assumed Generation Mix in Different ISOs

Territory	Fuel Type	Fuel Mix (%)
	Coal Power Plant	58.9%
	Natural Gas	5.4%
PJM	Oil	2.5%
	Nuclear	31.0%
	Hydro	1.1%
	Wind	0.1%
	Biomass	.9%
	Coal Power Plant	15.7%
	Natural Gas	38.4%
ISO-NE	Oil	8.2%
	Nuclear	28.0%
	Hydro	5.0%
	Wind	0%
	Non-Hydro Renew	4.7%
	Coal Power Plant	6.9%
	Natural Gas	49.3%
CA ISO	Oil	.8%
	Nuclear	15.9%
	Hydro	16.4%
	Wind	2.2%
	Biomass	3.2%
	Geothermal	5.2%

4. Developed Emissions Evaluation Tool

4.1 Description of Emission Tool

To support the evaluation, a detailed model was developed to compare the emissions of CO_2, SO_2 and NO_x for one of Beacon Power's planned 20 MW flywheel plants versus the three major types of conventional power generation technologies used today to perform frequency regulation. A spreadsheet based tool has been developed as part of this phase of the project. The tool has variable inputs on the different assumptions, discussed above. These inputs are used to calculate the emissions comparison per ISO region.

4.2 Variable Inputs to Emission Tool

An example of the different variable inputs is shown in Table 5. The input variables are shown for the flywheel. Similar input tabs are used for the different generator types. The table shows how the operation of the application is defined and where losses are accounted for during operation. In the model, these inputs are set up for each of the technologies being analyzed.

Table 5: Variable Input Page for Flywheel

Variables		
Max Cycles per day	24	cycles
Size	20,000	kW
Heat Rate(PJM)	10,128	btu/kWh
Charge/Discharge Time	0.25	hr
Total System Losses	14%	Percentage
Percentage Regulation Compliance	98.3%	Percentage
Cycle Time with No Load	0.5	hr
Solar System Providing No Load Power Toggle	No	

4.3 Output of Emission Comparison Tool

Table 6 is a summary of the emissions data obtained from modeling the operation of the Beacon Power flywheels against the other options for frequency regulation - a base-loaded coal plant, a "peaker" coal plant, base-loaded natural gas plant, a "peaker" gas plant and hydro pump storage are compared with the flywheel emissions output.

Table 6: Comparison of Emissions Output Data

Comparison	CO_2				SO_2				NOx			
	Per Cycle	Per Day	Per Year (tons)	Per Lifetime (tons)	Per Cycle	Per Day	Per Year (tons)	Per Lifetime (tons)	Per Cycle	Per Day	Per Year (tons)	Per Lifetime (tons)
PJM	lbs		tons		lbs		tons		lbs		tons	
Fly Wheel	1,704	40,889	7,462	149,246	11	263	48	962	3	71	13	259
Coal Baseload	3,526	84,615	15,442	308,845	24	572	104	2,088	6	149	27	543
Coal Peaker	3,814	168,907	30,825	616,509	26	1,454	265	5,307	7	378	69	1,381
Natural Gas Baseload	2,225	53,402	9,746	194,918	0	0	0	0	1	29	5	105
Natural Gas Peaker	1,188	61,490	11,222	224,439	0	0	0	0	1	42	8	154
Pump Storage	2,312	55,479	10,125	202,497	15	357	65	1,305	4	96	18	351
ISO-NE	lbs		tons		lbs		tons		lbs		tons	
Fly Wheel	1,218	29,232	5,335	106,697	3	74	14	270	1	32	6	115
Coal Baseload	3,479	83,496	15,238	304,759	15	356	65	1,300	5	114	21	416
Coal Peaker	3,764	166,672	30,418	608,354	16	905	165	3,303	3	271	50	990
Natural Gas Baseload	2,253	54,071	9,868	197,359	0	0	0	0	1	16	3	58
Natural Gas Peaker	1,203	62,260	11,362	227,249	0	0	0	0	0	23	4	85
Pump Storage	1,653	39,662	7,238	144,766	4	100	18	367	2	43	8	157
CA ISO	lbs		tons		lbs		tons		lbs		tons	
Fly Wheel	1,040	24,953	4,554	91,079	1	23	4	63	1	18	3	64
Coal Baseload	3,676	88,222	16,100	322,009	13	302	55	1,103	6	137	25	499
Coal Peaker	3,977	176,106	32,139	642,789	14	768	140	2,803	6	348	63	1,269
Natural Gas Baseload	2,221	53,297	9,727	194,534	0	0	0	0	1	22	4	80
Natural Gas Peaker	1,186	61,369	11,200	223,997	0	0	0	0	0	32	6	118
Pump Storage	1,411	33,857	6,179	123,577	1	23	4	85	1	24	4	87

These evaluation results are also summarized for each of the ISO territories in Table 7, Table 8, and Table 9 for the 20 year life cycle of the application.

Table 7: Emissions Comparison for PJM

Flywheel Emission Savings Over 20-year Life: PJM					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	149,246	149,246	149,246	149,246	149,246
Alternate Gen.	308,845	616,509	194,918	224,439	202,497
Savings (Flywheel)	159,599	467,263	45,672	75,193	53,252
Percent Savings	52%	76%	23%	34%	26%
SO2					
Flywheel	962	962	962	962	962
Alternate Gen.	2,088	5,307	0	0	1,305
Savings (Flywheel)	1,127	4,345	-962	-962	343
Percent Savings	54%	82%	n/a	n/a	26%
NOx					
Flywheel	259	259	259	259	259
Alternate Gen.	543	1,381	105	154	351
Savings (Flywheel)	284	1,122	-154	-105	92
Percent Savings	52%	81%	-148%	-68%	26%

Table 8: Emissions Comparisons for CAISO

Flywheel Emission Savings Over 20-year Life: CA-ISO					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	91,079	91,079	91,079	91,079	91,079
Alternate Gen.	322,009	608,354	194,534	223,997	123,577
Savings (Flywheel)	230,930	517,274	103,455	132,917	32,498
Percent Savings	72%	85%	53%	59%	26%
SO2					
Flywheel	63	63	63	63	63
Alternate Gen.	1,103	2,803	0	0	85
Savings (Flywheel)	1,041	2,741	-63	-63	23
Percent Savings	94%	98%	n/a	n/a	27%
NOx					
Flywheel	64	64	64	64	64
Alternate Gen.	499	1,269	80	118	87
Savings (Flywheel)	435	1,205	16	54	23
Percent Savings	87%	95%	20%	46%	26%

Table 9: Emissions Comparisons for ISO-NE

Flywheel Emission Savings Over 20-year Life: ISO-NE					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	106,697	106,697	106,697	106,697	106,697
Alternate Gen.	304,759	608,354	197,359	227,249	144,766
Savings (Flywheel)	198,062	501,657	90,662	120,552	38,070
Percent Savings	65%	82%	46%	53%	26%
SO2					
Flywheel	270	270	270	270	270
Alternate Gen.	1,300	3,303	0	0	367
Savings (Flywheel)	1,030	3,033	-270	-270	96
Percent Savings	79%	92%	n/a	n/a	26%
NOx					
Flywheel	115	115	115	115	115
Alternate Gen.	416	990	58	85	157
Savings (Flywheel)	301	875	-58	-31	41
Percent Savings	72%	88%	-101%	-36%	26%

4.4 Discussions of the Emission Comparison Results

The emissions comparisons estimates showed highly favorable results for the flywheel for reduction of CO_2. The developed model and analysis shows that the flywheel-based frequency regulation can be expected to create significantly less CO_2 for all of the generation technologies in every region, as well as less NO_x emissions for all technologies in the CAISO region.

Lifetime CO_2 savings for a flywheel-based regulation plant displacing a coal-fired plant in the PJM Interconnect area were estimated to be 159,599 tons for a base loaded coal plant and 467,263 tons for a peaker coal plant. This translates to projected reductions of 52% and 76%, respectively. In the ISO NE region, CO_2 reduction versus base loaded and peaker coal plants were projected to be 65% and 82%, respectively.

Lifetime CO_2 savings for a flywheel-based regulation plant displacing a base loaded natural gas-fired plant in California were estimated to be 103,455 tons, while CO_2 savings for a peaker gas plant were 132,917 tons. This translates to a projected savings of 53% and 59% in CO_2 emissions, respectively.

Lifetime CO_2 savings for a flywheel-based regulation plant displacing a pumped hydro plant were 26% in all three regions.

The flywheel system resulted in slightly higher indirect emissions of NO_x and SO_2 in PJM and ISO NE for gas-fired generation. This is because PJM and ISO NE's generation mix includes coal-fired plants as well as the low SO_2 emissions from natural gas power plants. The make-up electricity used by the flywheel and hydro systems reflects higher NO_x and SO_2 emissions from electricity generated in those areas.

5. Conclusions

In this report, KEMA compared the emissions from different frequency regulation generator technologies that actively participate in the ancillary services market, with the equivalent emissions associated with a 20 MW flywheel plant. A detailed model was developed to compare the emissions of CO_2, SO_2 and NO_x for a Beacon Power flywheel plant versus three types of commercially available power generation technologies used in the market to perform frequency regulation ancillary services.

The generation technologies compared included a typical coal-fired power plant, natural gas combustion turbine, and pumped storage hydro system. Emissions from the coal and natural gas-fired generation technologies result directly from their operation because they burn fossil fuels. In contrast, emissions for the flywheel and pumped hydro energy storage systems occur indirectly because they use some electricity from the grid to compensate for energy losses during operation.

The mix of power generation technologies and average system heat rates for fossil-based power generation systems varies across regions in the United States. To obtain a regionally adjusted emissions comparison, system data specific to three Independent System Operator (ISO) regions were examined: PJM (Mid-Atlantic), California ISO (CAISO), and ISO New England (ISO NE). Data for each of these ISOs was extracted from the most recent DOE EIA, and EPA eGrid databases. Model calculations assumed typical heat rate and efficiency data for each type of generation.

For coal and natural gas-fired generation, KEMA's research found that frequency regulation results in increased fuel consumption on the order of 0.5 to 1.5%. In this study 0.7% increased fuel consumption is used.

Based on the above data, model analysis showed that flywheel-based frequency regulation can be expected to produce significantly less CO_2 for all three regions and all of the generation technologies, as well as less NO_x and SO_2 emissions for all technologies in the CAISO region. The flywheel system resulted in slightly higher indirect emissions of NO_x and SO_2 in PJM and ISO NE for gas-fired generation. This effect was greatest in PJM because it has proportionally more coal-fired plants than ISO NE.

When the flywheel system was compared against "peaker" plants for the same fossil generation technologies, the emissions advantages of the flywheel system were even greater.

6. Recommendations

- All the data of this study was based on publicly available data from DOE, EPA and the different ISO sites. Some of the data may be dated in terms of the generation mix and generating efficiencies and heat rates. These results should be validated with direct ISO involvement in a future study.

- The assumed generation data is of a generic plant. It is thus limited in the details of specific frequency regulation plant efficiencies under different operating scenarios. It is proposed that a more in-depth analysis is performed based on specific coal or gas-fired generators. This should be done to calculate the specific emission savings that the flywheel installation can achieve at a specific installation in a certain ISO region.

- The frequency regulation control signal from a specific ISO could not be integrated into the current simplistic model. When a specific site is selected for frequency regulation, it is recommended to use specific generation data and integrate the relevant ISO frequency regulation control signal. This will be valuable to investigate the impact of partial discharge cycles on the lifetime emissions savings of the flywheel system compared to other generation technologies.

- The flywheel system has a much faster dynamic response compared to other frequency regulation generation technologies. The faster response or ramp-rate of the flywheel system can provide better frequency regulation results compared to conventional generation units. For comparison this improved performance could not be evaluated.

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Appendix 8.7
Cost Performance Report

Cost Comparison for a 20 MW Flywheel-based Frequency Regulation Power Plant

Beacon Power Corporation
KEMA Project: BPCC.0003.002
September, 2007
Final Report

Cost Comparison for a 20 MW Flywheel-based Frequency Regulation Power Plant

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KEMA-Inc. Project: BPCC.0003.001 Beacon Flywheel Project

Under Beacon Power Contract Number: 12952 of October 13, 2006
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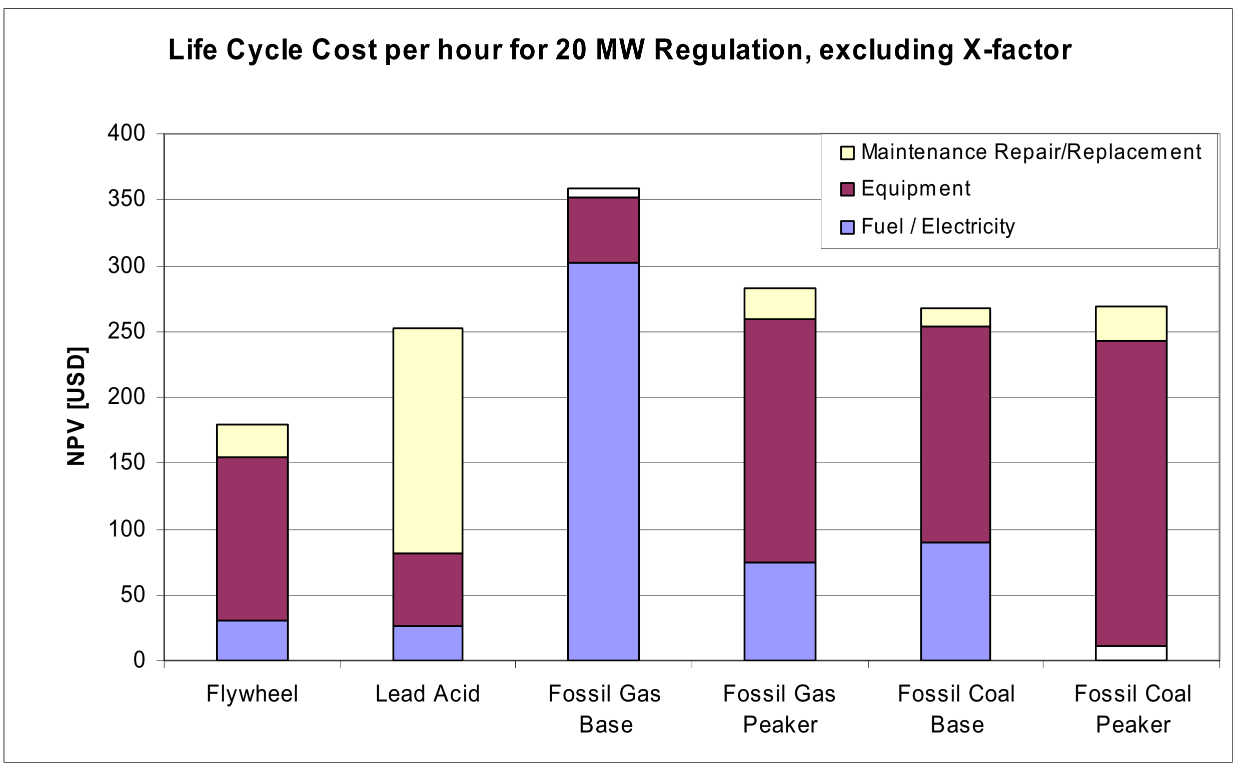
EXECUTIVE SUMMARY

KEMA, Inc. was commissioned by Beacon Power, with a contract funded by the US DOE through Sandia National Laboratories, to evaluate various performance aspects of the Beacon Power 20 MW flywheel-based frequency regulation power plant, including its life cycle cost to perform frequency regulation ancillary services in three Independent System Operator (ISO) markets. To support this evaluation, a model was created by KEMA to compare the life-cycle cost of the Beacon Power flywheel plant with four types of commercially available fossil power generation technologies used to perform frequency regulation services. The flywheel system was also compared with a lead acid battery storage system that could also be used to perform frequency regulation ancillary services, similarly to the flywheel system.

The analysis included preparation of a Life Cycle Cost model using Net Present Value analysis that reflected fixed and variable costs for regulation. As can be seen in **Error! Reference source not found.**, Beacon Power's flywheel is capable of delivering the regulation services at the lowest life cycle cost. Though a CO_2 market does not yet exist in the U.S., a section has been added to show the effects that a CO_2 market might have on the cost analysis. The graph also notes that it has excluded an X-factor. The



X-factor is the need for less

Figure 1: Life Cycle Cost per hour for 20 MW Regulation in the PJM region

total regulation resources due to fast response which could effectively decrease the LLC by a factor of 50 percent (assuming X = 2). While the X-factor is supported by several ISO studies, it has not yet been empirically confirmed with a full-scale plant for either the flywheel or battery technologies.

The model calculated hourly life cycle costs for flywheel regulation and for the competing technologies. Results of the analysis show that flywheel-based regulation can be expected to have significantly lower life cycle costs (LCC) compared to all of the competing technologies in the ISO regions studied. Within the PJM Interconnection, LCC for a base loaded gas-fired plant ("Fossil Gas Base" in **Error! Reference source not found.**) doing the same amount of regulation as a flywheel plant was estimated to be $47 million more than a flywheel plant, or just over 100 percent greater. For a base loaded coal-fired plant the additional LCC versus a flywheel plant was $23 million, or more than 49 percent greater. Similarly, the LCC increment for a lead acid battery-based system was estimated to be over $19 million, more than 41 percent greater compared to a flywheel plant.

Comparisons between the flywheel plant and gas and coal-fired peaker plants have been based on an equivalent cost basis. This equivalent cost is based on the NPV cost per regulation cycle, multiplied by the total amount of regulation cycles in the reviewed timeframe of 30 years. The amount of regulation cycles is the same for all technologies.

A gas-fired peaker plant would therefore require an additional $27 million in LCC, representing more than 57 percent greater effective life cycle cost. For a coal-fired peaker plant the comparative values were around $23 million and almost 50 percent higher, respectively.

Cost Components included in this analysis include:

1. Capital Cost for installing the equipment.
2. Operational Costs
    a. Fuel (or energy losses in case of flywheels and lead acid batteries)
    b. Maintenance and repair
    c. Periodic reinvestment
    d. Staff

e. Carbon Credit: Cost of CO_2 emissions, though there is not a market for CO_2 in the U.S., we have included a section that shows cost impacts for the various technologies if a CO_2 market existed in the U.S.

3. Reduction in operating life for thermal plants caused by providing regulation

4. Loss of availability for thermal plants due to providing regulation

Critical assumptions have been verified by industry experts and, where available, public data.. The cost evaluation under the scenarios listed above show favorable comparisons for the flywheel across all generation technologies. The remaining sections of the report provide the assumptions used in the modeling as well as further analysis and insights.

Data used in the report is based in part on average parameters for power plants considered "typical" for each of the comparison technology categories. Analysis using known historical cost components for a specific generating plant performing regulation can be expected to provide quantitatively different results relative to that plant. However, KEMA believes that use of representative plant data accurately portrays the costs for each *category* of technology.

Introduction

Beacon Power Corporation retained KEMA to perform a technology and cost evaluation of a 20 MW flywheel-based regulation plant and to compare the results against commercial fossil-based and pumped hydro solutions as well as a potential lead acid battery solution. The content of each phase was as follows:

Phase One: Emissions impact evaluation of the flywheel system compared to commercially utilized frequency regulation technologies bidding into the ancillary services market, and

Phase Two: Benefits of fast response to grid frequency regulation management and the regional grid; cost-performance analysis of the flywheel versus other commercially utilized frequency regulation technologies; and updated life-cycle emissions impacts incorporating the most recent emissions data from the US Environmental Protection Agency (EPA).

The balance of this Phase Two report is contained in the following sections:

Section 2: Benefits of Fast Response Regulation – discussion of the potential system-wide benefits of fast response, including both common and differential benefits for fast regulation tied into the grid at transmission and distribution levels.

Section 3: Cost Performance Analysis – evaluation of lifecycle cost-performance of flywheel-based regulation compared to commercially available technologies and lead acid batteries.

Section 4: Assumptions and Approach – listing of critical assumptions.

Section 5: Life Cycle Cost Evaluation – description of the model and output results.

Section 6: Conclusions – summary of major findings.

Section 7: References – sources for supporting data.

Appendix: Assumptions and Model Inputs – listing of model inputs for all the technologies.

Benefits of Fast Response Regulation

This section discusses the potential benefits of fast response regulation. These benefits are based on the findings of the California Independent System Operator (CAISO) and the California Energy Commission (CEC) with respect to the expected ability of fast response regulation to allow a reduction in the total system-wide capacity of regulation resources. This reduction is accomplished by using a mix of both fast response and slower conventional regulation generators. The section then reviews other possible benefits of fast regulation, some of which would be common to regulation resources integrated at either transmission or distribution voltages, and some of which would be specific to one or the other.

Reduction of System-wide Regulation Resources

In 2005 CAISO agreed to participate with Beacon Power in a contract awarded to Beacon by the CEC to demonstrate the value of frequency regulation using fast response flywheel energy storage. The CAISO supported the integration of the flywheel demonstration unit to its Energy Management System (EMS) and also helped determine the best way to optimize dispatch of the unit in order to take maximum advantage of the uniquely fast response capability of flywheel regulation.

CAISO's ACE Smoothing Algorithm

With the objective of fully exploiting the fast speed-of-response characteristics of flywheel technology, CAISO assigned Dr.Yuri Makarov of the CAISO to develop a new algorithm that would maximize system-wide benefits to the ISO. In particular, the new algorithm was designed to create maximum synergy between fast response flywheel-based regulation, and slower response conventional generation resources.[1]

ISO dispatching algorithms typically dampen the rapidly moving signal as determined by the instantaneous Area Control Error (ACE) in order to better match generator transient response capability and minimize the movement and directional changes of participating regulation generators. This helps reduce generator wear and tear and tripping events to levels considered acceptable by the owners of those resources as well as the ISO. However, signal damping can also have the effect of increasing the amount of regulation resources, and associated costs, needed for regulation.

Given their relatively slow speed-of-response, conventional regulation resources sometimes provide regulation in the wrong direction – after conditions have completely changed – and the grid is calling for regulation in the opposite direction. This occurs when the inertia of the slower responding generators does not allow power output to completely reverse in response within the intervals between ISO signals, which are typically every 4 to 6 seconds. A related undesirable effect of slow response resources is that they can sometimes partially cancel each other by simultaneously regulating in opposite directions. Both of these effects occur due to the inertial lag of conventional generators and the consequent necessity of signal dampening, and both contribute to the need for more system-wide regulation resources than would otherwise be required to maintain proper frequency limits on the grid.

[1] Dr. Makarov's work on frequency regulation, including frequency regulation algorithms and the 2X performance factor is referenced in several CAISO internal reports, as follows: "Suggested Algorithms to be Tested at San Ramon Test Facility," a California ISO document published 10/25/05, researched and written by Dr. Makarov; and "Relative Regulation Capacity Value of the Flywheel Energy Storage Resource," also researched and written by Dr. Makarov.

After CAISO developed and compared alternative methods for implementing frequency regulation, the best of these methods, termed the "ACE Smoothing Algorithm," was selected for the flywheel regulation demonstration tests that were subsequently performed over a period of 18-months in California. The "ACE Smoothing Algorithm" was specifically designed to extract maximum synergy between the faster, but energy limited flywheel regulation and slower but unlimited energy duration conventional generation resources. This was done by allowing the faster flywheel to regulate the most extreme high frequency regulation requirements which demand a faster ramp rate, while leaving the filtered lower frequency remainder to be handled by the conventional generating resources.

Figure 2 on the following page was provided as part of a February 2005 presentation by CAISO to the CEC. It graphically shows CAISO's goal to correct the majority of the ACE with faster responding regulation to make it easier for slower ramping regulators to follow the smooth orange line. As noted in **Figure 2**, the expected advantages of this control method include a reduction in the number of direction reversals of the conventional generators, greater ability to operate those slower units closer to their preferred operating point (POP), and a consequent reduction in the total amount of regulation resources needed for the total ISO system.

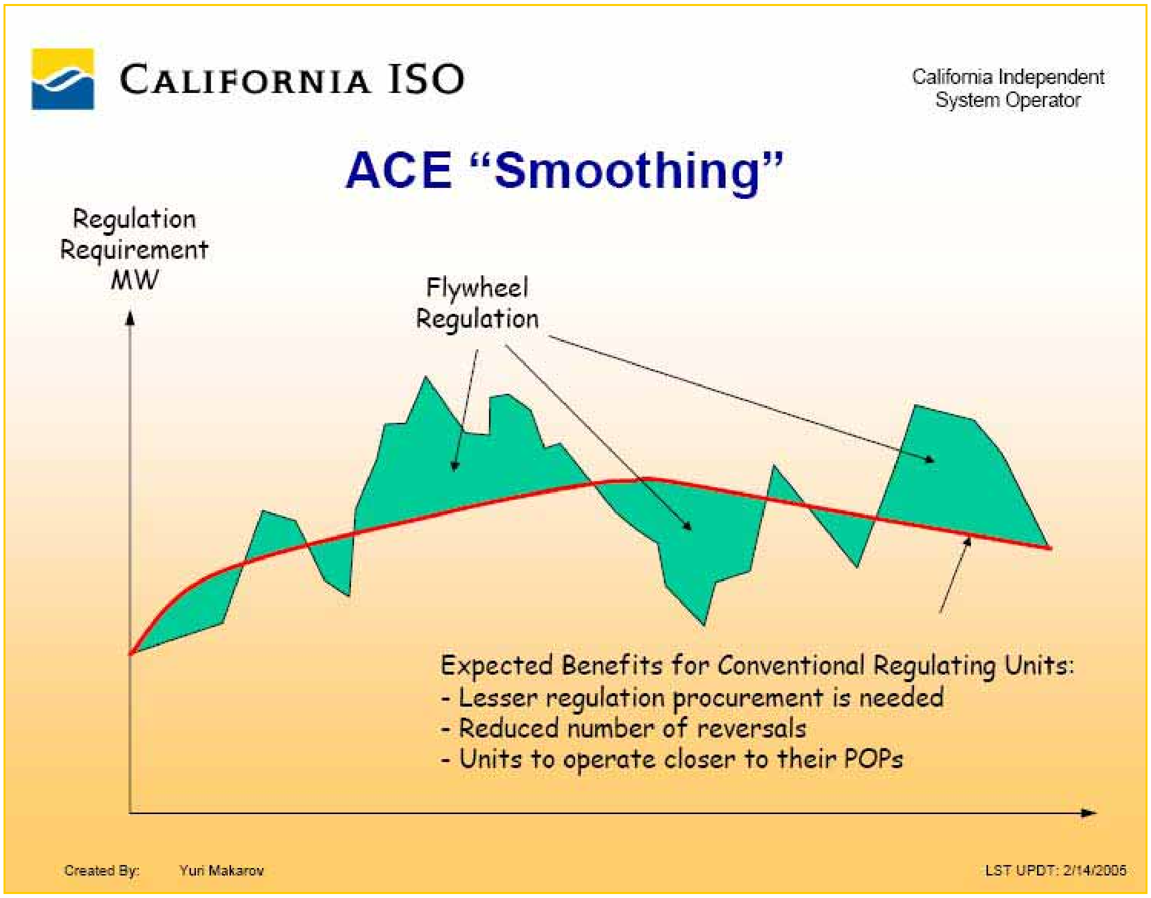


Figure 2: CAISO "ACE Smoothing"

The CAISO modeled the expected system-wide performance of the ACE Smoothing Algorithm assuming that fast regulation resources comprised one-fourth of total regulation assets based on regulating power. The model showed this combination would provide twice the regulation benefit compared to conventional automatic generation control (AGC) resources driven by traditional dispatching algorithms.[2] The CEC also supports the position that fast ramp rate regulation can be expected to have a higher value to the grid compared to slower regulation.[3]

[2] In an April 12, 2007 meeting at the CAISO, Dave Hawkins of the CAISO confirmed CAISO's view that fast responding flywheel regulation, if operated using the ACE Smoothing Algorithm may be twice as effective compared to conventional regulation resources operating alone. Other meeting attendees included Mike Gravely of the CEC and Bill Capp, Jim Arseneaux and Chet Lyons of Beacon Power Corporation.

[3] In its December, 2006 press release announcing the successful completion of testing for the flywheel demonstration system in California, the CEC stated: "In addition to the environmental and transmission benefits of flywheel technology, current research at Lawrence Berkeley National Laboratories indicates that 10 megawatts of fast-responding flywheel energy could

To understand the potential impact of faster regulation on comparative costs for all the technologies, KEMA's model was developed to represent this effect. The results are shown in Section 0 with the impact on the Life Cycle Cost (LCC) shown in Figure 8 These results use the same assumptions underlying the cost summary model, except that 1 MW of flywheel regulation is assumed to displace 2 MW of conventional regulation. This effect is referred to in this report as the "2X factor." Since lead acid batteries would have a possible response rate as fast as that for flywheels due to a similar power electronics interface, a similar result is shown for lead acid batteries in Figure 8. Figure 8 also assumes that lead acid batteries would displace twice as much conventional regulation resource.

For the purpose of this report, the comparative cost scenario modeled in Section 0. and shown in Figure 8 is regarded as an as-yet unproven possibility since the 2X factor has not yet been tested and validated with a full-scale commercial plant operating in the required proportions with other conventional regulation resources. Nevertheless the results in Section 0 present an intriguing potential picture of comparative costs for regulation technologies if the 2X factor is confirmed with a full-scale plant.

Beacon's flywheel technology can be integrated into the grid at either the transmission or distribution level. For 20 MW plants, integration will likely take place at or near transmission level to minimize the risk of grid disturbances. For smaller capacities, e.g., 5 MW and below, distributed regulation resources can be placed in the distribution level without much concern for disturbances. The sub-sections below identify and discuss other potential benefits of fast response regulation deployed at either the transmission or distribution level on the grid.

Reduced CO_2 Greenhouse Gas Emissions

As presented and discussed in the Phase I Report [1], KEMA's model analysis shows that flywheel-based frequency regulation can be expected to produce significantly less CO_2 for all three ISO regions that were modeled and compared to all of the conventional fossil and pumped hydro generation technologies. This benefit will apply to flywheel resources as well as Lead Acid Storage system resources integrated on either the transmission or distribution level.[4]

provide the grid with the equivalent energy of 20 megawatts or more of traditional slow-responding power plant energy."

[4] For a detailed discussion of CO_2 reduction benefits, see: "Emissions Summary Comparison for a 20 MW Flywheel-based Frequency Regulation Power Plant," KEMA, Inc., published in December, 2006.

Reduced Dependence on Fossil Fuel

In order for fossil-based plants to perform frequency regulation they must cycle up and down. For coal and natural gas plants, KEMA has found that the thermal cycling that fossil-based regulation plants undergo while performing frequency regulation reduces efficiency for the entire plant and causes them to consume in the range of 0.5 to 1.5% more fuel compared to what they would otherwise use if operated on a steady state basis. Adoption of flywheel-based regulation can reduce the amount of fossil fuel used by society to accomplish the regulation function, and that in turn would reduce national dependence on supplies of foreign fossil fuel from unfriendly and unreliable parts of the world.

Increased Peak and Base Load Generation Capacity

In its 2006 Long Term Reliability Assessment, the North American Electric Reliability Council (NERC) identified a looming shortage of peak generating capacity as a major concern requiring decisive action. Flywheel-based frequency regulation can be sited in the grid next to the existing installed base of fossil-based regulation plants. Where relevant, installing additional flywheel-based frequency regulation allows the recapture of the fraction of generation capacity that must otherwise be reserved to perform frequency regulation. This regained base load capacity will not require permitting or incur long construction cycles and delays since those fossil plants are already in place. In effect, the use of flywheel-based regulation would increase regional peak and base load generation capacity in proportion to the plants it displaces. In some regions, flywheel and battery-based regulation might conceivably qualify for some form of "capacity credit" which is paid by some ISOs to resource providers whose technology has the effect of increasing regional capacity. This estimated increase in capacity has not been quantified in this study.

Increased Transmission Capacity and Reduced Congestion

Flywheel systems sited in the distribution grid at medium voltage levels place the regulation service closer to the loads being regulated. Transmission and transformation losses associated with injecting regulating power on the transmission system could therefore be reduced or eliminated. This in turn would free up transmission line capacity, resulting in reduced or avoided congestion. However, the value of this benefit can only be quantified for specific locations by considering location-specific constraints. This estimated increase in transmission capacity has not been quantified in this study.

Additional Reduction of Grid Losses

The fluctuations of power flow in the transmission grids can be reduced due to the fact that the flywheel system is taking care of the fast fluctuations at the distribution level, while the average power is delivered by the generator/transmission system. The grid losses are much lower if the fluctuating power is not transmitted through the transmission system, but compensated directly at the source in the distribution system. Effectively, regulation plants embedded in the distribution system can reduce grid losses compared to more centrally located resources requiring greater allocation of transmission capacity. This estimated reduction in grid losses has not been quantified in this study.

Other Potential Grid benefits of Flywheel Systems

Provision of Grid Backup and 'Black Start' Ancillary Services

Once the flywheels are charged, they could also be used to supply selected critical loads or part of a grid in the event of a grid outage or interruption. Once an outage occurs, it will not be possible to supply regulation to the main grid anymore, so the system would be available for alternative applications. Even if the flywheels were partially empty before the outage, the flywheels could be charged with a smaller diesel generator than normally required to be used as a Black Start facility. This estimated benefit in Black Start has not been quantified in this study.

Support of Reactive Current / Voltage Control

The power electronics of the flywheel system have the ability to generate or absorb reactive power within the power range of the converters while performing regulation ancillary services. The control of reactive current may benefit grid operators since this allows the control of voltage – which in turn can help improve the quality of electricity delivered to end-users. This estimated benefit of VAr regulation and voltage support has not been quantified in this study.

Cost Performance Analysis

This section explains the rationale for KEMA's approach to structuring the cost comparison model. It also defines a regulation cycle and provides other background on key aspects of the cost model.

Life Cycle Cost Comparison Model

To simplify the 30-year cost comparison model, all of the technologies were assumed to be capable of generating equal annual revenues for the same 20 MW capacity of regulation resource. With the annual revenue for each technology thus fixed, the technology with the lowest combined present value for capital and operating costs can be considered the preferred technology. As explained below, this cost-centric approach to modeling probably underestimates the comparative advantage of the lowest cost technology.

In practice, low cost regulation resources are accepted into the ISO bid stack more often, thus maximizing their participation in the market and making it likely that annual revenues of a low cost bidder will be greater compared to bidders with higher life cycle costs who must bid higher prices. Limiting the model comparison to costs is a practical necessity because there is no reasonable way to make an accurate predictive determination of market-based revenue streams for each of the competing regulation technologies. Doing so would require an ISO system-wide model incorporating the operating characteristics for every regulation resource competing in a given market. This type of information is generally unavailable because it is considered proprietary to each of the regulation bidders.

Since revenues for higher cost regulation resources are probably lower relative to the revenues of bidders with lower life cycle cost, the conclusion that flywheel regulation technology has the lowest life cycle cost understates the comparative economic advantages of flywheel regulation.

Definition of the Hourly Regulation Cycle

The life cycle cost approach assumes the same regulation service for all technologies as defined in this paragraph. For modeling frequency regulation, the following regulation cycle is assumed: a cycle is defined as a 15 minute ramp up or charging period, a 15 minute ramp down or discharging period, and 30 minutes of maintaining steady state or normal operation. For a complete day, 24 cycles are examined. Partial charges and discharge cycles are not considered here. During the charge up as well as during the discharge phase, 20MW power is assumed. This defined cycle allows the creation of a relatively simple cost evaluation model that contains both full power range and high cyclic content. In practice, for real-life regulation a more volatile power profile will be evident, but the simplified cycle assumed in this report captures operating costs with reasonable accuracy while being easier to work with.

Technologies

KEMA evaluated the Life Cycle Cost for the technologies listed below providing frequency regulation at three locations: CAISO service area, PJM service area and the ISO New England (ISONE) service area. The technologies evaluated within these ISO regions were:

a) Beacon flywheel (nominal power at 20MW plant)

b) Conventional coal-fired fossil generating plants (base load and peaker units)

c) Conventional gas-fired fossil generating plants (base load and peaker units)

d) Lead acid battery storage

Approach

The Beacon flywheel was evaluated against the other generation technologies for the provision of frequency regulation. The following boundary assumptions were made:

a) Both the service profile and amount of regulation provided were considered identical for all the technologies

b) Cost factors for the different technologies were identified from literature where available. In certain cases KEMA made assumptions on the cost factors and benchmarked these assumptions with internal KEMA experts, external experts, and input from Beacon.

c) Assumptions for the key figures for all the technologies were provided to Beacon and collectively accepted before the analysis commenced.

d) The results of the Phase I - KEMA CO_2 emission analysis (see Reference 1) are incorporated in this Life Cycle Cost analysis as a cost for emitting carbon dioxide

e) As part of the assignment, a dedicated Life Cycle Cost evaluation tool was developed by KEMA. This proprietary tool is for internal Beacon Power use only.

f) The dedicated Life Cycle Cost tool is based on Net Present Value (NPV) calculations and incorporates costs that are either the direct result of providing the regulation service or additional costs incurred for providing the regulating service.

g) The results of these Life Cycle Cost calculations for providing regulation service are quantified both as a total NPV as well as in cost per hour.

Assumptions and Approach

This section identifies the cost components that are relevant to the regulation application. Each cost component is explained, and the numbers used in the model are given.

Cost Components

A dedicated NPV model is used to quantify the relevant costs allocated to regulation. The NPV model uses various costs that are captured on an annual basis.

The captured costs in the model include:

1. Capital Cost
2. Operational Costs
    a. Fuel (or electricity losses in case of Flywheels and Lead Acid Batteries)
    b. Maintenance
    c. Periodic reinvestment
    d. Staff
    e. Carbon Credit: Costs associated with CO_2 emissions were added in a final section to show the potential impact of carbon costs for each of the technologies assuming a CO_2 market emerges in the U.S. in the future
3. Lifetime reduction for thermal plants due to providing Regulation
4. Loss of availability for thermal plants due to providing Regulation
5. Depreciation

These costs are further discussed in the following paragraphs.

Where applicable, care has been taken to keep the assumptions between the emission analysis (Reference 1) and this cost comparison study as consistent as possible.

Capital Cost

Generally speaking, capital cost is the cost of installing a complete system. While that can be applied to the flywheel and the lead acid system, it is not a usable approach for the fossil systems since the total power plant is used only partially for regulation. Therefore, an alternative approach is taken. Only a fraction of the total power plant capital cost is allocated as regulation capital cost. The fraction is calculated by taking the ratio of the regulation power (in the case of this study, 20MW) compared to the nominal power plant rating (e.g., 400 MW for a base plant or 75 MW for a peaker plant).

Capital cost for the flywheel and lead acid systems is the total cost of the initial installment of the complete system, building, storage (flywheel or batteries) power electronics, monitoring & control, grid connection etc.

Table 1 below shows the data that is used in the Life Cycle evaluation for capital cost.

Table 1: Capital Cost for Each Technology

Technology	Capital cost [USD/kW]
Flywheel	1,630
Lead Acid	729
Gas Base	600
Gas Peaker	800
Coal Base	2,000
Coal Peaker[5]	1,000

[5] Note that currently only a few coal peakers are being constructed, so peaker capital cost was estimated.

Operational Costs

All costs occurring after the initial installment were allocated under operational costs. These are captured in the NPV cost model as annual costs and include fuel, cost due to CO_2 emissions, maintenance, reinvestments, staff, lifetime reduction and loss of availability. For the fossil plants, items under operational cost indicate that fraction of the cost that can be fairly *allocated* to the regulation service. For example, under maintenance, only the additional maintenance due to the fact that the plant is providing regulation service was included in the analysis.

Fuel for Fossils and Electricity Losses for Flywheels and Lead Acid Batteries

A fossil plant that is providing regulation services will have different fuel consumption compared to the same plant that is not providing regulation. The increased fuel cost is captured in this model. The increase in fuel consumption will lead to a higher cost for electricity generated by the power plant. This increased cost is allocated to regulation as fuel cost. The cause for the increased fuel consumption is two fold:

First, a plant providing regulation must reduce its output in order to both ramp up and ramp down during regulation. The reduced output will result in reduced efficiency of the plant, which increases fuel cost for the bulk power that is being generated by the plant. This means that all of the bulk power that is generated is actually generated at a higher fuel cost. Not all plants will always run at maximum optimal output, due to market schemes, portfolio use, rescheduling or other causes. Therefore increased fuel use due to running at partial load can only be allocated to regulation in a fraction of the total operating hours. Here a fraction of 50% of the total operating hours is chosen for the generators providing regulation services.

Second, a power plant that is cycling 20 MW above and below a given set point will have slightly increased fuel consumption. Measurements have shown that this increased fuel use ranges from 0.5% to 1.5%. In this study, an increase of fuel consumption of 0.7% is assumed for all fossil plants. This is considered conservative. Note that when this 0.7% factor is applied against the entire plant, the additional fuel consumption attributable to performance of the regulation function becomes a significant cost factor.

Assumed base and increased fuel costs for the fossils is as shown in Table 2 on the following page. The table shows increased fuel consumption as a percentage that includes both of the effects discussed above.

Table 2: Fuel Cost Allocated to Regulation for Fossil Power Plants

Type of Power Plant	Fuel Cost		
	Base Cost [USD/kWh]	Increased Fuel consumption allocated to regulation [%]	Additional Fuel Cost allocated to regulation [USD/MWh]
Coal Base	0.0196	2.7	0.5292
Coal Peaker	0.0300	2.7	0.8100
Gas Base	0.0480	3.7	1.7760
Gas Peaker	0.0732	3.2	2.3424

These values are based on average power plants in the existing USA generation portfolio, and assuming a 5-6 USD/MMBTU energy price. As Flywheels and Lead Acid batteries also consume energy from main stations, the electricity cost for flywheels and Lead Acid Systems is assumed to be .05 USD/kWh.

Carbon Credit: Cost Associated with CO_2 Emissions

The cost for carbon emissions is calculated by multiplying tons of CO_2 emitted for each type of plant (from the emission study) by an assumed cost per ton for carbons emission. The cost per ton for carbon emissions is not set in the United States since there is currently no CO_2 market mechanism. However, it appears likely that a CO_2 market will emerge in the U.S. or else the U.S. will join the international market before too long. In Europe, a CO_2 market is in place. The CO_2 cost in the model of 17 USD/ton of CO_2 is the 2008 forward market value/cost on the EU emission markets for emitting an additional ton of CO_2.

Carbon Cost is only allocated to the fossil plants, since only these generate direct emissions. The flywheel and lead acid systems have zero direct CO_2 emissions because they do not consume fuel. Hence, for the purposes of this model they have no direct CO_2 related costs.

As a CO_2 market in the U.S. does not currently exist, calculations of total cost excluded CO_2. However, in section 5.2 "Output of Cost Model", an additional section was added to show the impacts that such a market might have on the cost calculations for each of the technologies.

Maintenance

A line item in the model for annual maintenance cost is identified for each technology. This represents the additional maintenance above and beyond regular maintenance due to the fact that a plant is providing regulation. Since the lead-acid and flywheel systems are installed specifically for regulation, all maintenance is allocated to regulation. Cost data used was obtained from the following sources:

- **Flywheel system**: annual maintenance cost provided by Beacon Power.
- **Lead acid system**: allocated annual maintenance is 2% of the initial installation or capital cost. This number is an estimate based on lead-acid systems described in the EPRI/DOE Handbook (see Reference 2) and has been validated by Sandia National Labs' experts (Reference 3)
- **Fossil systems**: 0.5% additional maintenance is used. This number is based on limited empirical data available on this topic (Reference 5). The data does not allow differentiating between the different fossil plants. Therefore, 0.5% is used for the base and peaker plants, gas as well as coal.

Periodic Reinvestment

This item includes all costs for equipment made after the initial installation and includes items such as new battery cells, new bearings, etc. This item is most relevant for the flywheel and lead acid systems, as similar costs have already been captured under maintenance for the fossil technologies. For the flywheel system, the model incorporates data provided by Beacon Power.

For the lead acid system, the lifetime of the battery cells is evaluated based on amp-hour counting. This results in a 1.14 yr lifetime, meaning a replacement of the full battery pack every 7^{th} year. The cost of this battery pack replacement is allocated under periodic investments.

For the fossil-based generating plants, no periodic reinvestments were allocated to regulation.

Staff

This cost item includes the staff responsible for operations of the systems allocated to regulation. Again, this means for fossil generators only the additional staff due to the regulation service, and is estimated to be 1 FTE (full-time-equivalent) for all fossil systems.

For flywheel systems, the staff requirement as provided by Beacon power is 1.25 FTE.

Based on larger battery systems, such as the utility installation for PREPA, Metlakatla and GVEA, a total of 3 FTE is assumed for the lead acid system (see Reference 3).

Lifetime Reduction for Thermal Plants Due to Regulation

Thermal plants are subject to unplanned outages or trips. Each trip will cause the plant to go off-line, which results in increased maintenance, inspection and repair. Each trip will also result in a reduction of remaining lifetime due to increased stresses and loading of the components in the plants, such as the boiler or the turbine blades.

Typically, a trip results into 10-20 hours of lifetime reduction. Empirical data has shown that the amount of unplanned trips is directly related to how often and how fast the output of a plant changes (Reference 7). Regulation causes the output and rate of change (in output) to change a great deal. Trips caused by the performance of regulation by thermal plants also contribute to decreased system availability and loss of regulation revenue for thermal plants

The referenced empirical data shows that the amount of unplanned trips a generator experiences annually increases to approximately 15 trips due to regulation services. See

Figure 3 on the following page.

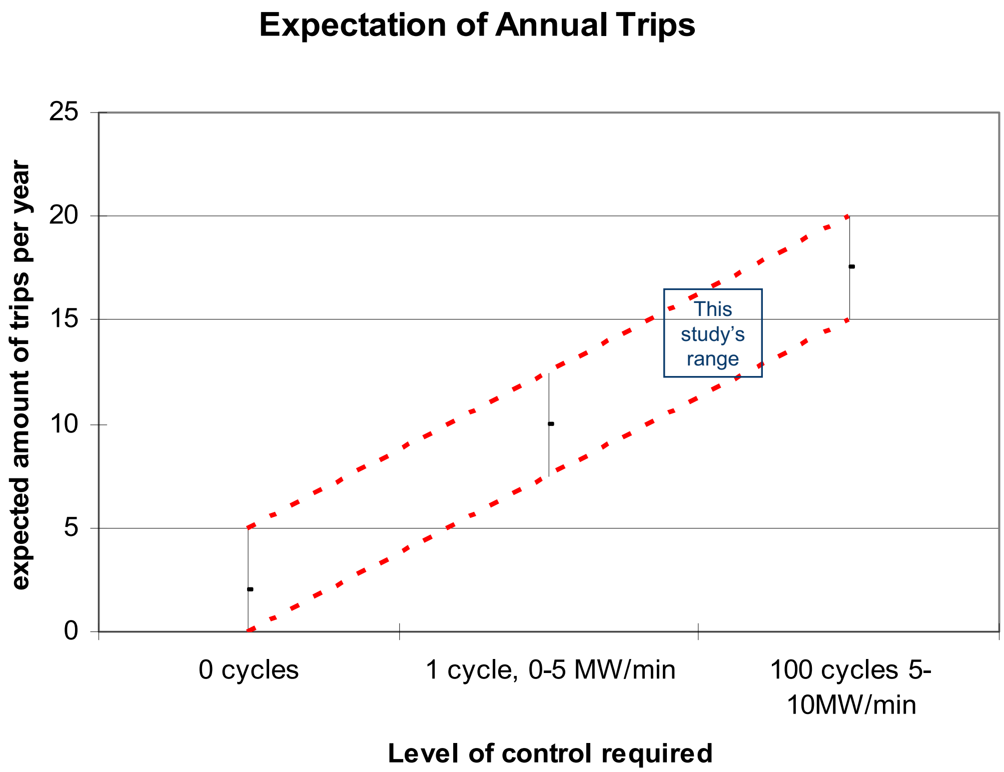


Figure 3: **Increase in annual unplanned trips based on level of control required by power plant**

The resulting lifetime reduction is in the range of 150-300 hours annually, or 4,500-9,000 hours in a 30 year evaluation frame, equaling up to 1 year reduction in life due to the fact that the plant is performing regulation services. The model assumes a 1 year reduction in lifetime. In the NPV model a reinvestment is made in the 30th year, equal to 1/30 of the original capital investment. (References 4, 5 and 7.)

Loss of Availability of Thermal Plants Due to Regulation

During scheduled maintenance a power plant is not available for power generation or regulation services until the unit is brought back on-line. Depending on the issues at hand, this downtime can be hours, days or even weeks if repairs are required. This translates into a reduced availability and has an associated cost.

Limited empirical data shows that a plant providing regulation will have a reduced annual availability of 500 hours (from about 8,500 hours operation annually down to about 8,000 hours). This equates to a reduction of availability of 6%. See

Figure 4.

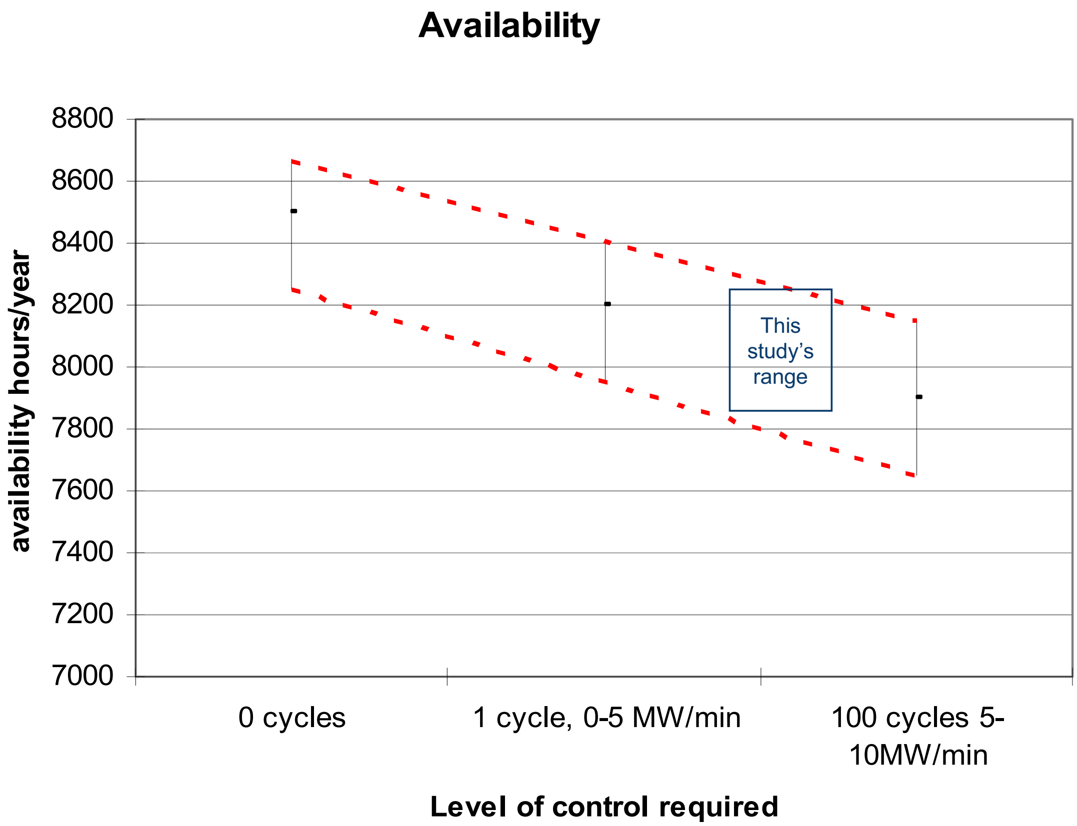

Availability
8800
8600
8400
8200
8000
7800
7600
7400
7200
7000
availability hours/year
This study's range
0 cycles
1 cycle, 0-5 MW/min
100 cycles 5-10MW/min
Level of control required

Figure 4: Loss of availability due to the level of control on a power plant

Note that this estimated additional costs associated with the loss of availability of the plants due to regulation are currently not reflected in the model. For the purpose of this study it is assumed that the loss of regulation service due to tripping or other maintenance issues associated with thermal plants will be filled in by other plants because there are enough other plants in the ISO's control area to make up any shortfall. In the cost model for this study no costs due to tripping are levied against the thermal plants. In practice, tripping will reduce revenue from regulation, but such reduction is not reflected in this study since all the technologies are assumed to develop the identical revenue per year for identical nameplate capacity. The error this introduces is not considered significant enough to warrant a different modeling approach. (References 4, 5 and 7.)

Depreciation

While federal and state depreciation has an influence on the financial modeling of capital intensive investments with long lifetimes, including the technologies compared in this study, this KEMA LCC model results do not incorporate the effects of depreciation tax shield. This was due to the uncertainty of selecting the correct depreciation schedule for each of the assets and the impossibility of selecting a set of typical tax circumstances for assumed owners of the technologies. For example, an asset owner with limited corporate earnings might pay little or no taxes, whereas a highly profitable corporation could be subject to high taxation on net plant revenues. Owners who pay high taxes would benefit comparatively more from the income tax shield – which would artificially skew the comparison between technologies. In short, since financial performance can be heavily driven by tax treatment, KEMA's life cycle cost model excluded such tax effects in order to develop an accurate comparative cost-based life cycle financial analysis.

In practice, the depreciation tax schedules for the technologies being compared probably vary considerably since they reflect Federal policy which has as one of its objectives the encouragement of advanced new technologies. For example, the tax schedule for a standard fossil-based thermal power plant might be 20 or 30 year straight line depreciation, whereas for advanced energy storage technologies like flywheels and batteries – accelerated 5 or 7-year Modified Accelerated Cost Recovery System (MACRS) depreciation might well apply. If the tax shield effects of those shorter depreciation schedules can be captured they can effectively reduce the capital cost by 15 percent or more, so differences in tax treatment are worth noting.

Learning Curve and Cost Changes

Over the years, some of the cost components will change. Today, we do not have the knowledge of future costs for items such as fuel, maintenance, capital cost, etc. For "what if" analysis, the Developed Dedicated Life Cycle Cost model includes, for relevant cost components, a line item for "annual cost increase," which is set to zero. The argument for this assumption is that it avoids skewing results in favor of the most extravagant claims about expected future cost breakthroughs for given technologies. The counterargument is equally valid. Not projecting cost breakthroughs, especially for the newest technologies, artificially inflates future costs. For example, the amount of energy stored in one of Beacon's 4th generation flywheels is about four times greater than one of its 3rd generation flywheels, but it does not cost four times as much. Advances in battery technology are also occurring at a rapid rate. Nevertheless, since the thrust of this cost comparison study is aimed at providing a fair cost comparison of these technologies as they stand today, no annual cost decrease due to performance improvements is assumed. The effect of cost reduction due to volume production was, however, included in the model. The cost calculation of the flywheel was based on volume-driven cost reductions achieved by the 10th plant.

Life Cycle Cost Evaluation

Description of Cost Tool

To support the evaluation, a detailed model was developed to compare the life cycle cost of providing the same regulation service. Technologies compared included a flywheel system, a lead-acid system, and fossil generators using either gas or coal (both base load and peaker plants). A spreadsheet tool has been developed with variable inputs for key assumptions, as discussed above. These inputs are used to calculate and compare cost for each of the technologies for each of three ISO regions.

This model assumes a 30 year life and costs for the 10th plant. The primary cost driver for the flywheel technology is the cost of the flywheel itself. The cost of the 10th plant is projected as $1,630 USD / MW. of capacity, which includes all ancillary systems.

An example of the input section of the model is shown in Table 3 on the following page. These parameters can be changed in the general section of the inputs or in the technology specific sections for each technology. Assumptions are on a single page, allowing quick and consistent modeling of the technologies and cost components. The model may also be used to perform further "what-if" analysis. The losses for the complete flywheel system are included.

				unit	
general	evaluation timeframe		30	year	
	initial year for NPV calculations		2,007		
	nr of cycles in 1 year		8,760		
	nr of cycles in 30 year		262,800	cycles	
	FTE cost		80,000	USD/a	
	electricity cost - station power		0.05	USD/kWh	
	electricity cost - transaction power		0.07	USD/kWh	
	annual price increase for station power electricity cost		0.0%	/yr	
	annual price increase for transaction power electricity cost		0.0%	/yr	
	nominal power of Regulation unit		20	MW	
	corporate tax		35%		
	Cost of Debt		7.5%		
	Cost of Debt (incl Tax Shield)		4.9%		
	Cost of Equity		7.5%		
	Equity		40%		
	Debt		60%		
	Discount Rate for Cash Flow		7.50%		
	Regulation revenu per service hour		52.50	USD/MW service hour	
	revenue for Regulation		9.2	MUSD/a	
	CO2 emissions		17	USD/ton	
	annual price increase for CO2 emissions		0.0%	/yr	
	X-factor: multiplier for fast Flywheels		2	X	
	X-factor: multiplier for fast Lead acid		2	X	
	region selection for emmissions		numeric average		
	nominal rating for base case fosil plants		400	MW	
	nominal rating for peaker fosil plants		75	MW	

Flywheel				unit		
	operating hours per day		24			
Investments	Flywheel (complete) system					
	10th plant		1630	USD/kW		
	value to use in cost model	10th plant	1630	USD/kW		
operational costs	maintenance					
	general annual maintenance		11,600	USD/MW		
	annual price increase for maintenance		0.0%	/yr		
	annual price increase for replacements		0.0%	/yr		
	losses					
	Total Losses		12,421,680	kWh /year		1
	required staff for operation		1.25	FTE/yr		
CO2 emissions	PJM		7,462	ton/a		
	CAISO		4,554	ton/a		
	ISO NE		5,335	ton/a		
	numeric average		5,784	ton/a		
	no emission		0			
	value to use in cost model		numeric average		5,784 ton/a	
other	depreciation scheme for plant		MACRS 20 Years			

Table 3: Example of Model Input Page

Output of Cost Comparison Tool

The model is set up in a modular and flexible way. This allows the output to be presented in different ways. This paragraph will show the results in several graphs. Each will be explained and summarized.

Total Life Cycle Cost of the Technologies

Figure 5 shows the total Life Cycle Cost (LCC) for the PJM area over the complete lifetime of a 20 MW regulating plant in Million 2007 US dollars. While the graph seems to indicate that both peaker plants are able to provide regulation for less money, peaker plants are assumed to be operational only 8 hours per day, not 24. This means that the peakers deliver one-third of the service per 24-hour period compared to the non-peaker thermal plants or the storage technologies. Thus they cannot be directly compared to the other technologies without a cost adjustment shown on the following page.

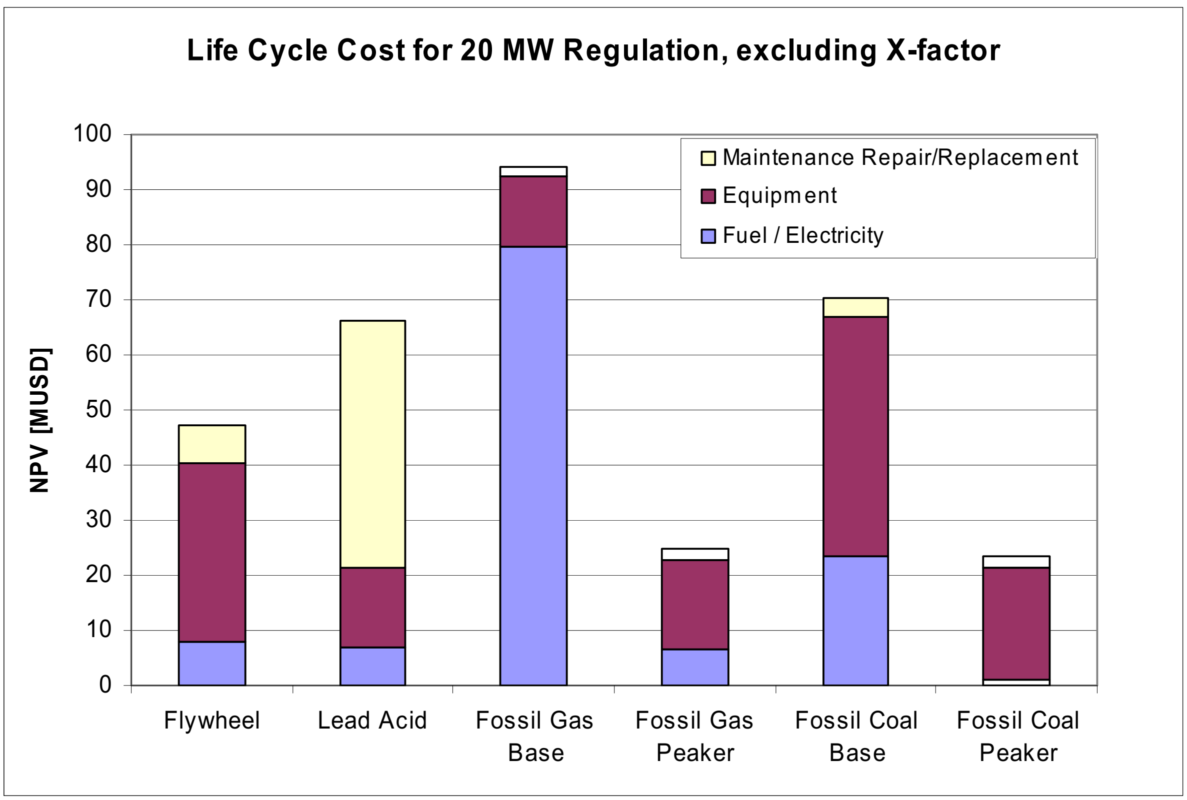


Figure 5: Life Cycle Cost for Regulation does not reflect the total cost picture as peaker plants are operational only 8 hour per day

From this figure the life cycle cost (LCC) for a base loaded gas-fired plant ("Fossil Gas Base" in Figure 5) doing the same amount of regulation as a 20 MW flywheel plant was estimated to be $47 million more than a flywheel plant. For a base loaded coal-fired plant the additional LCC compared to a flywheel plant was estimated as $23 million. Similarly, the LCC increment for a lead acid battery-based system was estimated to be $19 million greater compared to a flywheel plant. These values are calculated in the KEMA developed LCC tool and can be visually verified in Figure 5.

Hourly Life Cycle Cost Comparison

As mentioned in the previous paragraph, the cost comparison needs to compensate for the effect that peaker plants actually only operate on an 8 hour per day basis while the other technologies are operational 24/7. The compensation is achieved by standardizing the LCC to "cost per hour" for providing Regulation. This provides a fair and equitable comparison as shown below in Figure 6 below. The LCC per hour to provide 20 MW of regulation is presented in 2007 US dollars.

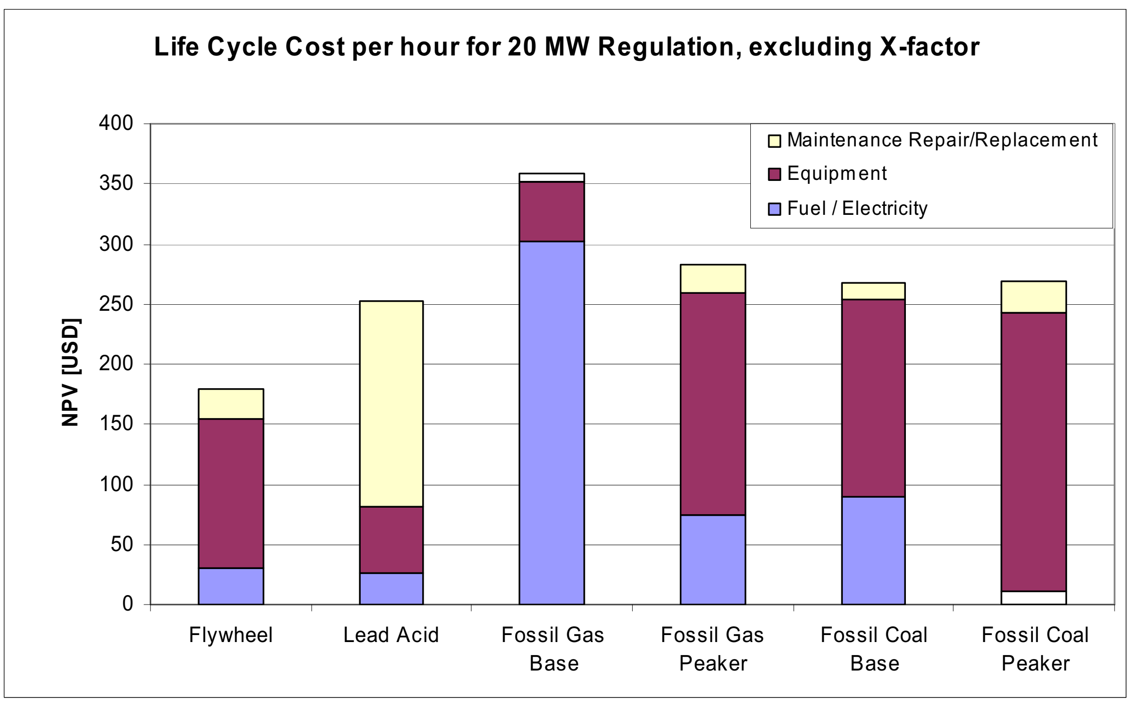


Figure 6: Hourly LCC allows for a sound comparison between technologies

Figure 6 clearly shows that the Beacon Flywheel systems have the lowest hourly life cycle cost for regulation, reflecting both initial capital costs and operational costs. The graph also shows that cost for regulation service for the peaker plants is significantly less compared to the base plants. The main reason for this is the lower fuel cost for the peaker plants. Since a base plant has a higher rating, the increased fuel consumption for the entire 380MW plant (400-20) is allocated to regulation, while for the peaker this cost component is only calculated over 55MW (75-20).

Comparisons between the flywheel plant and gas and coal-fired peaker plants have been based on an equivalent cost basis. This equivalent cost is based on the NPV cost per regulation cycle, multiplied by the total amount of regulation cycles in the reviewed timeframe of 30 years. The amount of regulation cycles is the same for all technologies. A gas-fired peaker plant would therefore require an additional $27 million in LCC, representing more than 57 percent greater effective life cycle cost. For a coal-fired peaker plant the comparative values were around $23 million and almost 50 percent higher, respectively. This 30 year LCC result is calculated for providing 24/7 regulation services.

Region Independent Results for Evaluated Regions

Regions will differ in technology life cycle costs only if CO_2 markets exist. This is because regions have different generation mixes and hence, different emission profiles. In the absence of CO_2 markets, little differences in projected costs exist across regions. This is shown in Figure 7 below:

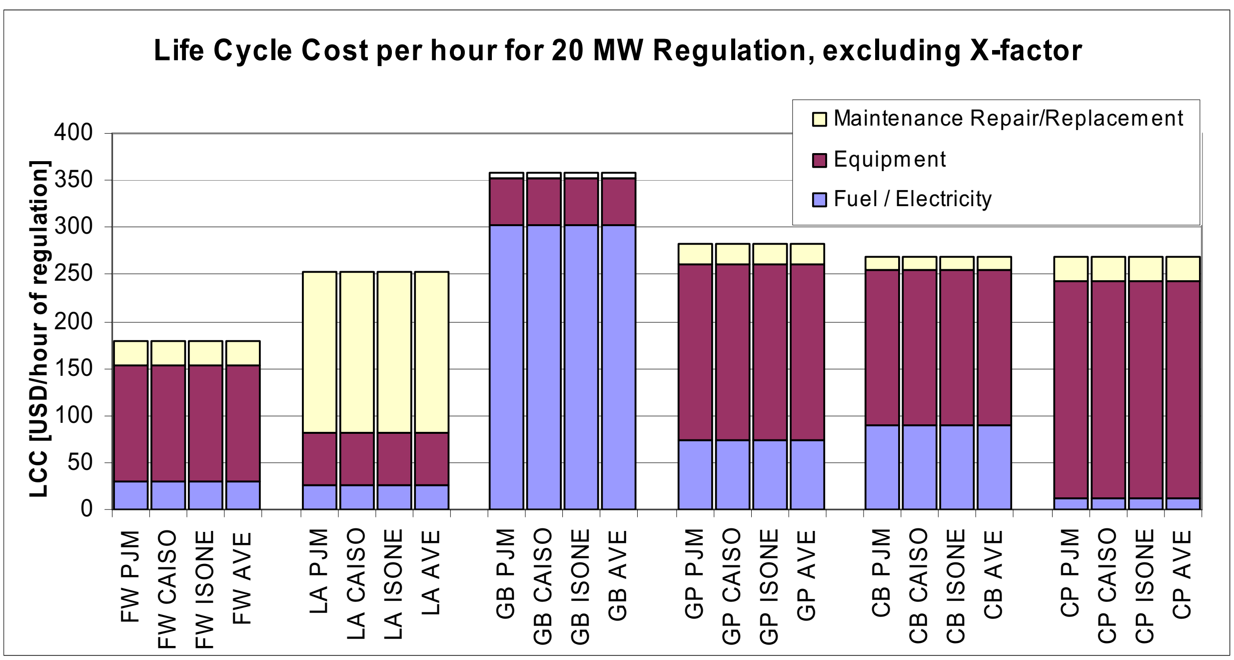


Figure 7: Comparison of the hourly LCC over the PJM, CAISO and ISONE regions shows little deviation in cost

Figure 7 [6] shows that hourly LCC cost is identical for all three regions. Therefore, we conclude that hourly LCC costs are comparable for the three regions and can be fairly represented either by a numerical average of the three or by any one of the three.

Effect of X-factor on Hourly LCC

While the efficacy of the X-factor is supported by several ISO studies, the X-factor has not yet been empirically confirmed with a full-scale plant for either the flywheel or battery technologies. Nevertheless, for illustrative purposes, Figure 8 shows that should the flywheel and/or battery technologies obtain higher regulation revenues from ISOs in consideration of potential X-factor regulation advantages (primarily the need for less total regulation resources due to fast response), costs for those technologies could effectively decrease by a factor of 50 percent (assuming X = 2).

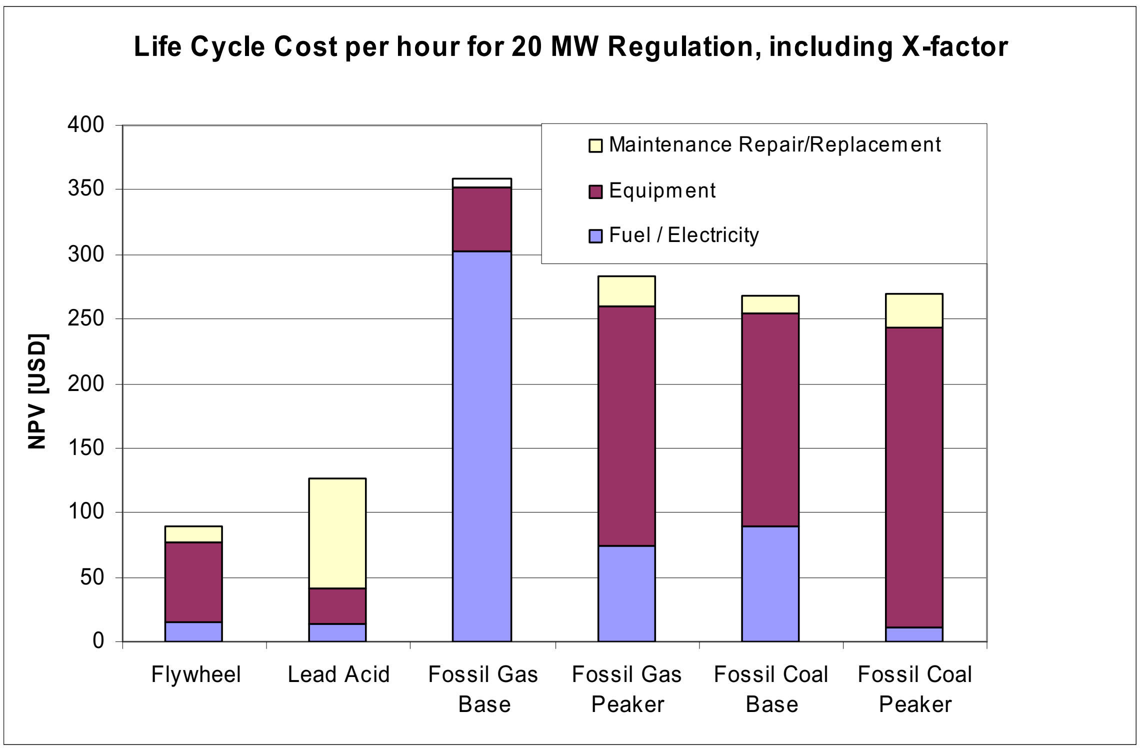


Figure 8: Illustrative results for an X-factor

[6] FW = Beacon's Flywheel; LA = Lead Acid system; GB = Gas Base-load Fossil plant; GP = Gas Peaker plant; CB = Coal Base-load fossil plant; CP = Coal peaker plant; AVE = numerical average of PJM, CAISO and ISONE area.

Total Life Cycle Cost of the Technologies with CO_2 Included

Though a CO_2 market does not exist in the U.S., it is likely that one may soon exist. Hence, for each of the cost calculations shown in the previous section, the model was also run with the assumption that a market existed. In this scenario, the value of CO_2 was set to $17 USD/ton. The results of the analysis are shown for each of the cases examined in the previous sections of the "Model Output."

Total Life Cycle Cost of the Technologies

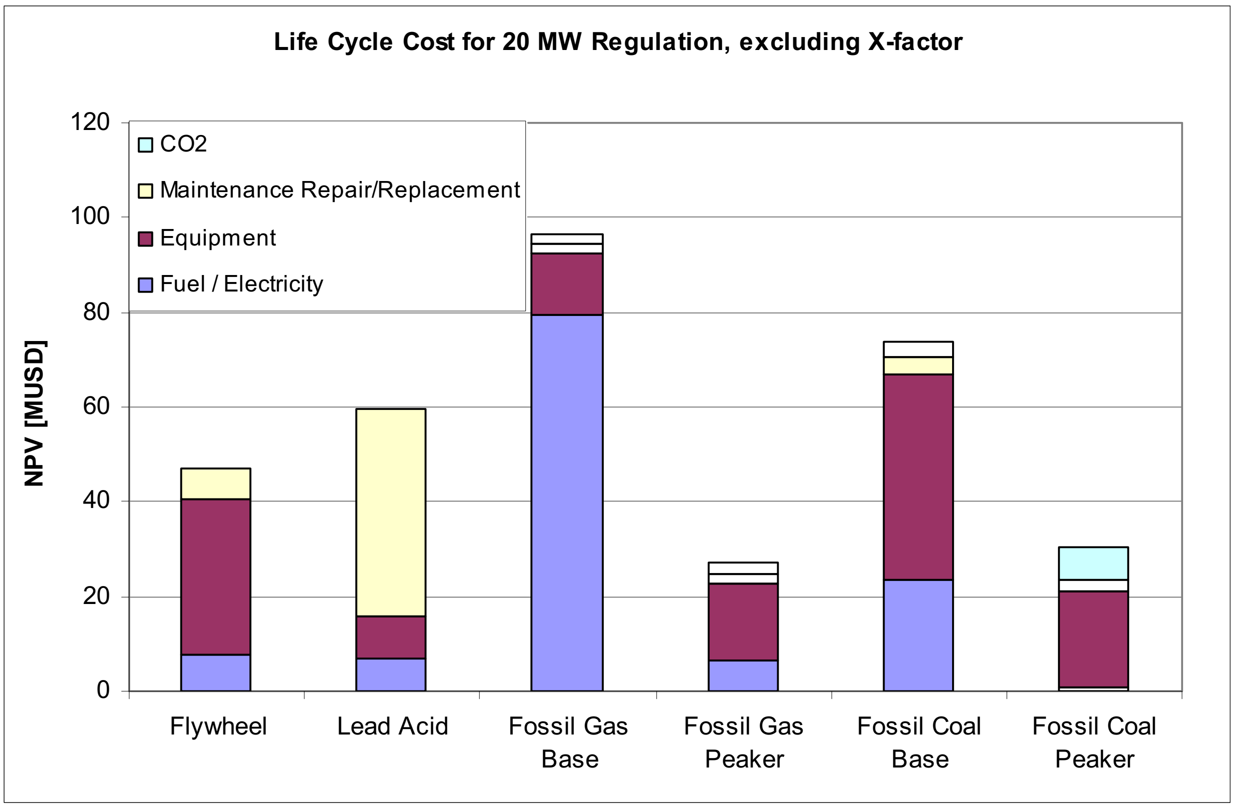


Figure 9: Life Cycle Cost for Regulation does not reflect the total cost picture as peaker plants are operational only 8 hour per day

From this figure the life cycle cost (LCC) for a base loaded gas-fired plant ("Fossil Gas Base" in Figure 9) doing the same amount of regulation as a 20 MW flywheel plant was estimated to be $49 million more than a flywheel plant. For a base loaded coal-fired plant the additional LCC compared to a flywheel plant was estimated as $27 million. Similarly, the LCC increment for a lead acid battery-based system was estimated to be $19 million greater compared to a flywheel plant. These values are calculated in the KEMA developed LCC tool and can be visually verified in Figure 9.

Hourly Life Cycle Cost Comparison

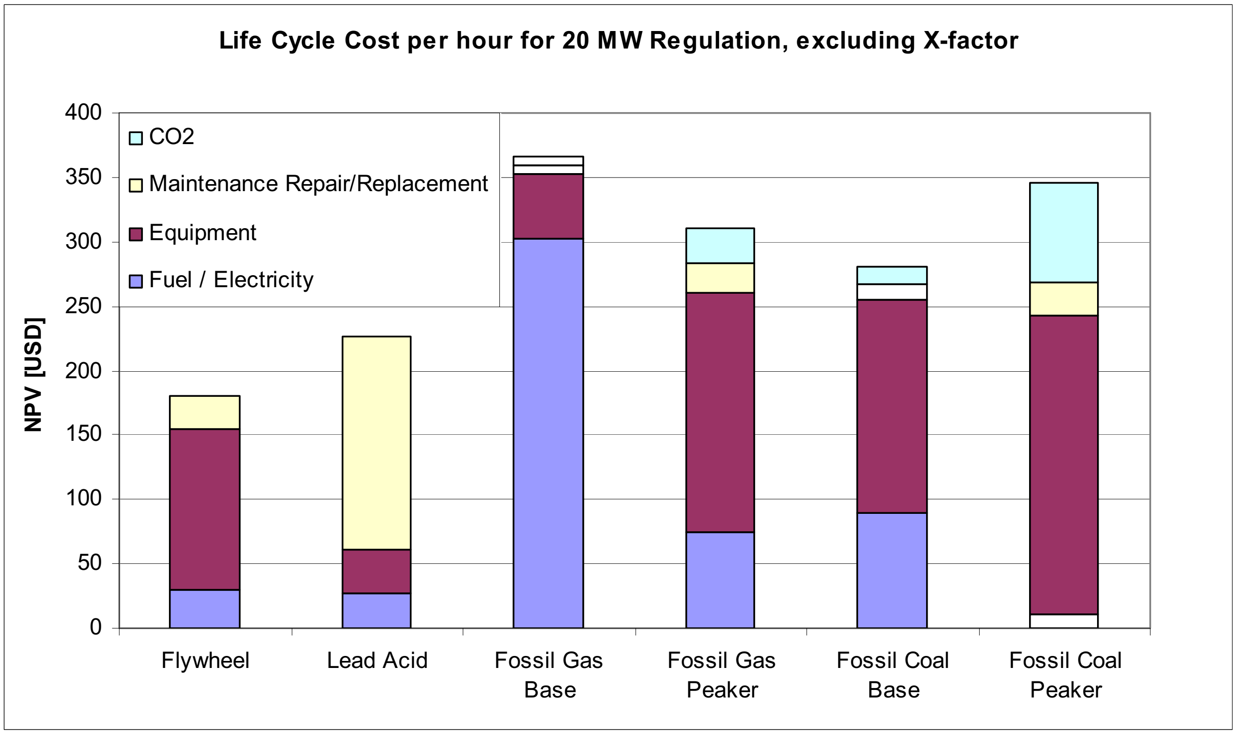


Figure 10: Hourly LCC allows for a sound comparison between technologies

With an active CO_2 market, a gas-fired peaker plant would require an additional $34 million in LCC, representing more than 73 percent greater effective life cycle cost. For a coal-fired peaker plant the comparative values were around $44 million and almost 92 percent higher, respectively. This 30 year LCC result is calculated based on the provision of 24/7 regulation services.

Region Independent Results for Evaluated Regions

When comparing the different ISO regions, the CO_2 cost component would have an impact because of the different generation mixes in each region and is represented in the graph shown below in Figure 11.

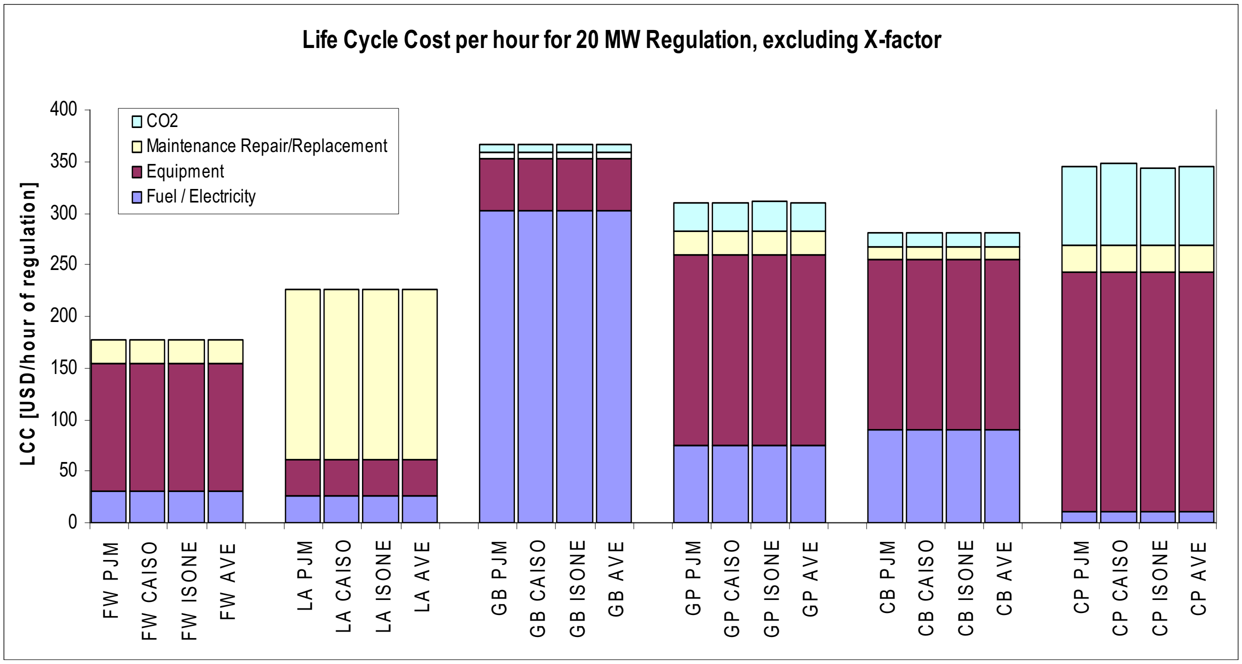


Figure 11: Comparison of the hourly LCC over the PJM, CAISO and ISONE regions shows little deviation in cost

Effect of X-factor on Hourly LCC

While the efficacy of the X-factor is supported by several ISO studies, the X-factor has not yet been empirically confirmed with a full-scale plant for either the flywheel or battery technologies. Nevertheless, for illustrative purposes, Figure 12 shows that should the flywheel and/or battery technologies obtain higher regulation revenues from ISOs in consideration of potential X-factor regulation advantages (primarily the need for less total regulation resources due to fast response), costs for those technologies could effectively decrease by a factor of 50 percent (assuming X = 2).

In Figure 12 on the next page, CO_2 costs are included in the totals.

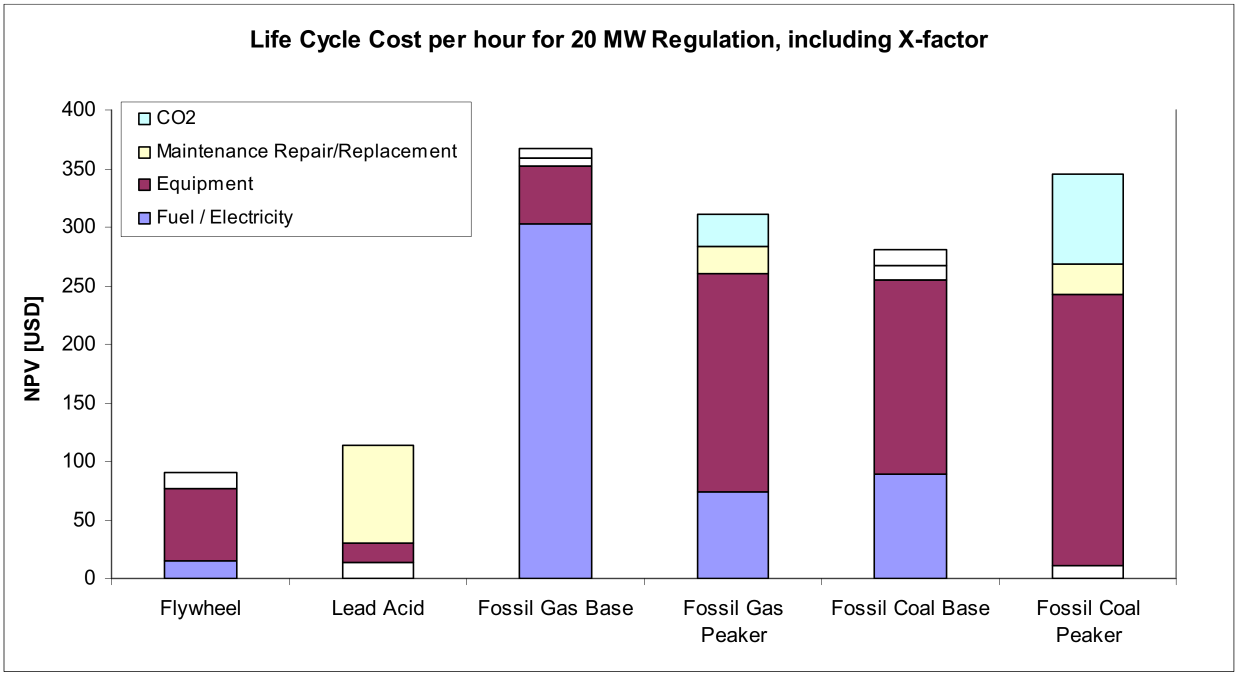


Figure 12: Illustrative results for an X-factor

Conclusions

In this report, KEMA compared the life cycle cost (LCC) for different regulation technologies. A model was developed to compare the cost of regulation service for a Beacon Power flywheel-based plant versus four types of commercially available power generation technologies and a lead acid storage system.

The model calculated the hourly LCC for regulation for all evaluated technologies. The results show that flywheel-based frequency regulation can be expected to show significantly lower life cycle costs for all of the competing regulation technologies in all of the ISO regions studied.

The generation technologies evaluated included typical base loaded and peaker coal-fired and natural gas combustion turbine plants. For the flywheel and the lead acid battery systems, 100 percent of costs are direct costs, since these systems provide only regulation service. For the fossil plants, relevant cost components required for the performance of regulation were identified and allocated to the regulation function. Model calculations assumed typical heat rate and efficiency data for each type of generation.

While the additional benefits of fast response is supported by several ISO studies, the X-factor performance multiplier has not yet been empirically confirmed with a full-scale plant for any fast responsive technology. Therefore the LCC comparisons summarized below do not incorporate any potential future cost reduction benefit due to the 2X factor.

Most regions show similar LCC comparisons due to the fact that only the cost associated with CO_2 emissions are differentiating the different regions, all other costs are assumed to be similar. Within the PJM Interconnection for example, the LCC for a base loaded gas-fired plant doing the same amount of regulation as a flywheel plant was estimated to be $47 million more than a flywheel plant, or just over 100 percent greater. For a base loaded coal-fired plant the additional LCC versus a flywheel plant was $23 million, or more than 49 percent greater. Similarly, the LCC increment for a lead acid battery-based system was estimated to be over $19 million, more than 41 percent greater compared to a flywheel plant.

Comparisons between the flywheel plant and gas and coal-fired peaker plants have been based on an equivalent cost basis. This equivalent cost is based on the NPV cost per regulation cycle, multiplied by the total amount of regulation cycles in the reviewed timeframe of 30 years. The amount of regulation cycles is the same for all technologies.

A gas-fired peaker plant would therefore require an additional $27 million in LCC, representing more than 57 percent greater effective life cycle cost. For a coal-fired peaker plant the comparative values were around $23 million and almost 49 percent higher, respectively.

If the impact of a potential future CO_2 market is included, cost differences increase even more favorably for the flywheel power plant.

In summary, the flywheel regulation plant has a significantly lower LCC compared to all of the competing technologies studied for all of the ISO regions considered, both with or without consideration of any possible future cost impacts due to the emergence of a domestic CO_2 market and related costs

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Appendix – Assumptions and Model Inputs

				unit	
general	evaluation timeframe		30	year	
	initial year for NPV calculations		2,007		
	nr of cycles in 1 year		8,760		
	nr of cycles in 30 year		262,800	cycles	
	FTE cost		80,000	USD/a	
	electricity cost - station power		0.05	USD/kWh	
	electricity cost - transaction power		0.07	USD/kWh	
	annual price increase for station power electricity cost		0.0%	/yr	
	annual price increase for transaction power electricity cost		0.0%	/yr	
	nominal power of Regulation unit		20	MW	
	corporate tax		35%		
	Cost of Debt		7.5%		
	Cost of Debt (incl Tax Shield)		4.9%		
	Cost of Equity		7.5%		
	Equity		40%		
	Debt		60%		
	Discount Rate for Cash Flow		7.50%		
	Regulation revenu per service hour		52.50	USD/MW service hour	
	revenue for Regulation		9.2	MUSD/a	
	CO2 emissions		17	USD/ton	
	annual price increase for CO2 emissions		0.0%	/yr	
	X-factor: multiplier for fast Flywheels		2	X	
	X-factor: multiplier for fast Lead acid		2	X	
	region selection for emmissions		numeric average		
	nominal rating for base case fosil plants		400	MW	
	nominal rating for peaker fosil plants		75	MW	

Flywheel				unit		
	operating hours per day		24			
Investments	Flywheel (complete) system					
	10th plant		1630	USD/kW		
	value to use in cost model	10th plant	1630	USD/kW		
operational costs	maintenance					
	general annual maintenance		11,600	USD/MW		
	annual price increase for maintenance		0.0%	/yr		
	annual price increase for replacements		0.0%	/yr		
	losses					
	Total Losses		12,421,680	kWh /year		1
	required staff for operation		1.25	FTE/yr		
CO2 emissions	PJM		7,462	ton/a		
	CAISO		4,554	ton/a		
	ISO NE		5,335	ton/a		
	numeric average		5,784	ton/a		
	no emission		0			
	value to use in cost model		numeric average		5,784	ton/a
other	depreciation scheme for plant		MACRS 20 Years			

Figure 13: General and Flywheel Assumptions and Model Inputs

Lead Acid			unit	
	operating hours per day	24		
Investments	Batteries	150	USD/kWh	
	shipping	0	USD/kWh	
	batteries	3.75	MUSD	
	Power electronics to grid	165	USD/kW	
	Balance of plant	100	USD/kW	
operational costs	maintenance			
	general annual maintenance	2%	of original investment	
	annual price increase for maintenance			
	annual price increase for replacements	0.0%	/yr	
	losses			
	battery losses charging	5.0%	of actual charge load	
	battery losses discharging	5.0%	of actual discharge load	
	station losses	10%	of actual load	
	interconnection losses	0%	of actual load	
	energy battery losses charging	2190000	kWh /year	
	battery losses discharging	2190000	kWh /year	
	station losses	8760000	kWh /year	
	interconnection losses	0	kWh /year	
	total losses	13,140,000	kWh /year	
	required staff for operation	3	FTE/yr	
sizing	Cell voltage	2	V	
	Amp hour rating	100	Ah per cell	
	DC voltage	700	V	
	nr of cells in series (per string)	350.0		
	installed capacity per string	70	kWh	
	cycle depth	20%		
	energy per regulation cycle	5,000	kWh	
	required nameplate capacity	25,000	kWh	
	nr of strings	357.1		
	total nr of cells	125,000		
lifetime	nameplate cycle life time	2,000	cycles	
	nameplate Ah life	200,000	Ah	per cell
	nameplate Ah life	71,428,571	Ah	for total installed system
	Ah per regulation cycle	7,143	Ah	
	life time in regulation cycles	10,000		
	life time in years	1.14	yrs	
CO2 emissions	PJM	7,894	ton/a	
	CAISO	4,817	ton/a	
	ISO NE	5,643	ton/a	
	numeric average	6,118	ton/a	
	value to use in cost model	numeric average		6,118 ton/a
other	depreciation scheme for plant	MACRS 20 Years		
	depreciation scheme for battery	linear 1 Year		

Figure 14: Lead-acid Assumptions and Model Inputs

Fossil power plant Coal Base Load			unit	
Investments	fossil plant system cost	2000	USD/kW	
	nominal rating of fossil plant	400	MW	
	operating hours per day	24		
	Annual capacity Factor	100%		
operational costs	maintenance			
	general annual maintenance	0.5%	of original investment	
	annual price increase for maintenance and replacements	0.0%	/yr	
	increased fuel consumption due to regulation	0.7%	of all bulk power being generated	
	increased fuel consumption due to lower efficiency	2%	of all bulk power being generated	
	base fuel cost	0.0196	USD/kWh	
	annual price increase for fuel (coal)	0.0%	/yr	
	required staff for operation	1	FTE/yr	
lifetime				
	shelf life time	30	year	
	life time reduction due to regulation	1	yr/30 years	
		97%		
CO2 emissions	PJM	15,442	ton/a	
	CAISO	16,100	ton/a	
	ISO NE	16,100	ton/a	
	numeric average	15,881	ton/a	
	value to use in cost model	numeric average		15,881 ton/a
other	control band for Regulation	5%	of nominal power	
	reduction in availability	6%	of time	
	derating' due to required control band	1.00		
	depreciation scheme for plant	linear 30 Years		

Fossil power plant Coal peaker			unit	
Investments	fossil plant system cost	1000	USD/kW	
	nominal rating of fossil plant	75	MW	
	operating hours per day	8		
	Annual capacity Factor	33%		
operational costs	maintenance			
	general annual maintenance	0.5%	of original investment	
	annual price increase for maintenance and replacements	0.0%	/yr	
	increased fuel consumption due to regulation	0.7%	of all bulk power being generated	
	increased fuel consumption due to lower efficiency	2%	of all bulk power being generated	
	base fuel cost	0.013	USD/kWh	
	annual price increase for fuel (coal)	0.0%	/yr	
	required staff for operation	1	FTE/yr	
lifetime				
	shelf life time	30	year	
	life time reduction due to regulation	1	yr/30 years	
		97%		
		8	hr	
CO2 emissions	PJM	30,825	ton/a	
	CAISO	32,139	ton/a	
	ISO NE	30,418	ton/a	
	numeric average	31,128	ton/a	
	value to use in cost model	numeric average		31,128 ton/a
other	control band for Regulation	27%	of nominal power	
	reduction in availability	6%	of time	
	derating' due to required control band	1.00		
	depreciation scheme for plant	linear 30 Years		

Figure 15: Coal Fossil Assumptions and Model Inputs

Fossil power plant base load gas			unit	
Investments	fossil plant system cost	600	USD/kW	
	nominal rating of fossil plant	400	MW	
	operating hours per day	24		
	Annual capacity Factor	100%		
operational costs	maintenance			
	general annual maintenance	0.5%	of original investment	
	annual price increase for maintenance and replacements	0.0%	/yr	
	increased fuel consumption due to regulation	0.7%	of all bulk power being generated	
	increased fuel consumption due to lower efficiency	3%	of all bulk power being generated	
	base fuel cost	0.048	USD/kWh	
	annual price increase for fuel (gas)	0.0%	/yr	
	required staff for operation	1	FTE/yr	
lifetime				
	shelf life time	30	year	
	life time reduction due to regulation	1	yr/30 years	
		97%		
CO2 emissions	PJM	9,746	ton/a	
	CAISO	9,727	ton/a	
	ISO NE	9,868	ton/a	
	numeric average	9,780	ton/a	
	value to use in cost model	numeric average		9,780 ton/a
other	control band for Regulation	5%	of nominal power	
	reduction in availability	6%	of time	
	derating' due to required control band	1.00		
	depreciation scheme for plant	linear 30 Years		

Fossil power plant gas peaker			unit	
Investments	fossil plant system cost	800	USD/kW	
	nominal rating of fossil plant	75	MW	
	operating hours per day	8		
	Annual capacity Factor	33%		
operational costs	maintenance			
	general annual maintenance	0.5%	of original investment	
	annual price increase for maintenance and replacements	0.0%	/yr	
	increased fuel consumption due to regulation	0.7%	of all bulk power being generated	
	increased fuel consumption due to lower efficiency	2.5%	of all bulk power being generated	
	base fuel cost	0.07319	USD/kWh	
	annual price increase for fuel (gas)	0.0%	/yr	
	required staff for operation	1	FTE/yr	
lifetime				
	shelf life time	30	year	
	life time reduction due to regulation	1	yr/30 years	
		97%		
CO2 emissions	PJM	11,222	ton/a	
	CAISO	11,200	ton/a	
	ISO NE	11,362	ton/a	
	numeric average	11,261	ton/a	
	value to use in cost model	numeric average		11,261 ton/a
other	control band for Regulation	27%	of nominal power	
	reduction in availability	6%	of time	
	derating' due to required control band	1.00		
	depreciation scheme for plant	linear 30 Years		

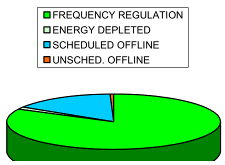
Figure 16: Gas Fossil Assumptions and Model Inputs

Appendix 8.8

Detailed Data for Field Trial Test

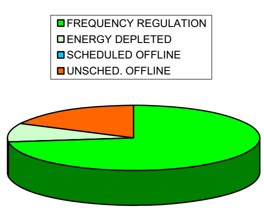
NYSERDA Run Data Monthly Summary Sheet **Date:** **July 06 - Feb 07**

		July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Average
DAILY SUMMARY	FREQUENCY REGULATION	73%	75%	80%	84%	84%	71%	81%	81%	76%
	ENERGY DEPLETED	9%	12%	13%	11%	11%	10%	3%	3%	9%
	SCHEDULED OFFLINE	18%	12%	7%	4%	4%	18%	15%	15%	12%
	UNSCHED. OFFLINE	0%	1%	0%	0%	0%	1%	1%	1%	0%
	Total	100%	100%	100%	100%	100%	100%	100%	100%	100%
ON-LINE PERFORMANCE	Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs	88.9%	84.9%	85.6%	89.0%	87.7%	87.2%	95.6%	96.8%	89%
	Deviation Excluding Depleted Time	2.7%	3.6%	2.2%	2.6%	6.9%	2.7%	5.8%	2.4%	4%
	Deviation Including Deplete Time	7.9%	10.4%	7.9%	7.1%	10.5%	7.1%	7.0%	3.4%	8%



NYSERDA Run Data Monthly Summary Sheet **Date: July, 2006**

		Percent	Hours
DAILY SUMMARY	FREQUENCY REGULATION	73%	17.6
	ENERGY DEPLETED	9%	2.1
	SCHEDULED OFFLINE	0%	0.0
	UNSCHED. OFFLINE	18%	4.3
	Total	100%	24.0
ON-LINE PERFORMANCE	Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs	88.9%	
	Deviation Excluding Depleted Time	2.7%	
	Deviation Including Deplete Time	7.9%	



DAILY SUMMARY

July , 2006 NYSERDA SEM Performance Summary

Date	Freq Reg	Energy Depleted	Total Online Hrs	Offline Unsched	Offline Sched	Availability	Deviation	Deviation w/ depletion	Max KW	Setpoint KW	Cutout Speed RPM	Max FW's	Comment
1-Jul	11.16	2.50	13.66	0.00	10.34	81.74%	1.88%	11.28%	100	10	17,000	7	PJM up regulating from noon until 10 PM
2-Jul	19.05	4.77	23.82	0.18	0.00	79.39%	2.46%	12.01%	100	10	17,000	7	
3-Jul	9.13	0.15	9.29	0.02	14.70	98.15%	4.15%	4.49%	100	10	17,000	7	MC Software change: Implementing and debugging Robust Vibes Handler.
4-Jul	13.57	0.26	13.83	0.21	9.97	96.68%	2.10%	3.39%	100	0	17,000	7	PJM up regulating from 8 AM to 6 PM
5-Jul	22.06	1.90	23.96	0.05	0.00	91.90%	6.66%	10.00%	100	10	17,000	7	
6-Jul	12.82	0.26	13.08	0.09	10.83	97.34%	2.04%	3.25%	100	15	17,000	7	PJM up-regulating from 12 PM to 11 PM
7-Jul	23.32	0.68	24.00	0.00	0.00	97.18%	1.98%	3.11%	100	15	17,000	7	
8-Jul	15.94	4.67	20.61	0.00	3.39	77.33%	6.98%	16.06%	100	15	17,000	6	Lost comm. With ECM #6 at 5 AM.
9-Jul	17.63	4.46	22.09	0.00	1.91	79.82%	5.91%	15.84%	100	15	17,000	6	ECM #6 down: Late tonight we realized ECM 6 was not communicating and offlined it
10-Jul	7.79	0.28	8.07	0.00	15.93	96.51%	2.07%	3.67%	100	15	17,000	6	System was left in MANUAL mode until 7:10 and then the reg signal flatlined at 100% discharge unitl 4 PM.
11-Jul	20.61	1.80	22.41	0.00	1.58	91.94%	2.44%	5.94%	100	15	17,000	6	1 Hr+ shut down fixing a Linux file redirection problem
12-Jul	15.56	1.28	16.84	0.00	7.17	92.42%	2.06%	4.83%	100	15	17,000	7	Downtime due to vibe fault
13-Jul	15.13	4.85	19.97	0.41	3.62	74.22%	2.10%	15.93%	100	15	17,000	6	First attempt to fix the vibes handler to remove SUPERVISED IDLE.
14-Jul	20.64	3.36	24.00	0.00	0.00	86.00%	2.64%	11.01%	100	15	17,000	6	
15-Jul	19.24	4.76	24.00	0.00	0.00	80.16%	2.72%	14.95%	100	15	17,000	6	
16-Jul	19.43	4.57	24.00	0.00	0.00	80.95%	3.22%	15.44%	100	15	17,000	6	ECM #6 functioned intermittently.
17-Jul	13.28	1.97	15.25	0.03	8.72	86.92%	2.49%	10.63%	100	15	17,000	6	ECM #6 removed from the system.
18-Jul	9.36	0.52	9.88	0.00	14.13	94.79%	1.99%	4.59%	60	15	17,000	6	First part of day: vibes shut down the system. A fix will be installed tomorrow. Up-regulating from 10 PM to Midnight.
19-Jul	15.07	2.14	17.21	0.00	6.79	87.57%	2.33%	8.33%	60	15	17,500	5.5	DSAT on ECM 7. Software upgrade + bad regulation signal: 2 hrs scheduled down time +/-. Up-regulating from midnite through 5 AM
20-Jul	6.64	1.23	7.87	0.00	16.13	84.35%	2.19%	9.21%	60	15	17,500	6	Software problem (see yestarday)… System down from about 8 AM on
21-Jul	22.47	1.28	23.74	0.26	0.00	93.62%	1.63%	3.37%	100	15	17,500	6	
22-Jul	21.64	2.28	23.91	0.09	0.00	90.15%	1.99%	6.27%	60	15	17,500	6	
23-Jul	16.74	1.85	18.60	0.00	5.40	90.04%	2.21%	7.50%	60	15	17,500	6	FW 6 down. Freq regulation command was up-regulating for about 6 hours
24-Jul	21.94	0.74	22.68	0.00	1.32	96.72%	2.06%	3.57%	60	15	17,500	6	FW #6 out of commission 1/2 the day. System down 1 hour due to diagnostics. # 6 back on line.
25-Jul	22.09	1.91	24.00	0.00	0.00	92.06%	2.25%	5.47%	60	15	17,500	7	
26-Jul	22.50	1.50	24.00	0.00	0.00	93.75%	2.42%	4.86%	60	15	17,500	7	
27-Jul	23.79	0.21	24.00	0.00	0.00	99.14%	2.40%	2.78%	60	15	17,500	7	
28-Jul	22.05	1.96	24.00	0.00	0.00	91.86%	2.26%	5.84%	60	15	17,500	7	
29-Jul	21.69	2.31	24.00	0.00	0.00	90.37%	2.07%	6.43%	60	15	17,500	7	Rerun of 7/29 without up-regulating
30-Jul	20.66	3.34	24.00	0.00	0.00	86.10%	2.27%	7.90%	60	15	17,500	7	
31-Jul	21.41	2.59	24.00	0.00	0.00	89.23%	2.25%	7.81%	60	15	17,500	7	
Avg	**17.56**	**2.14**	**19.70**	**0.04**	**4.26**	**88.95%**	**2.72%**	**7.93%**					

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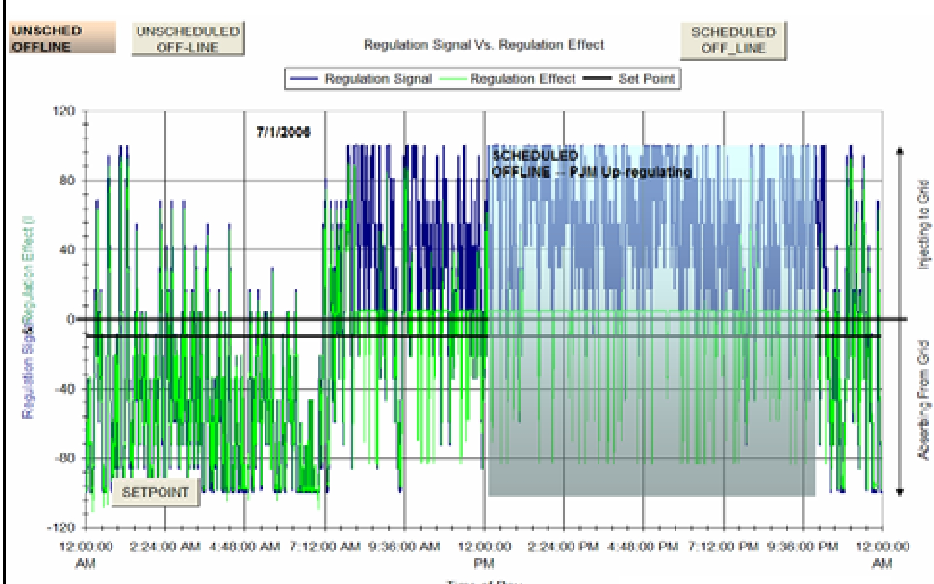

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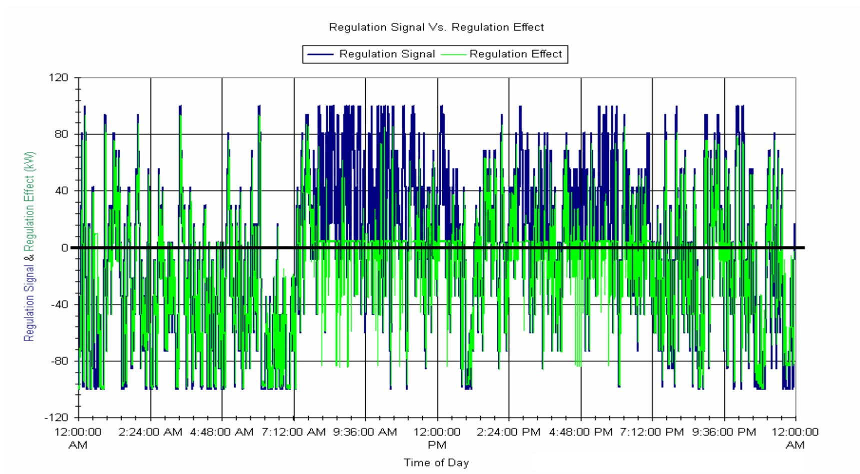

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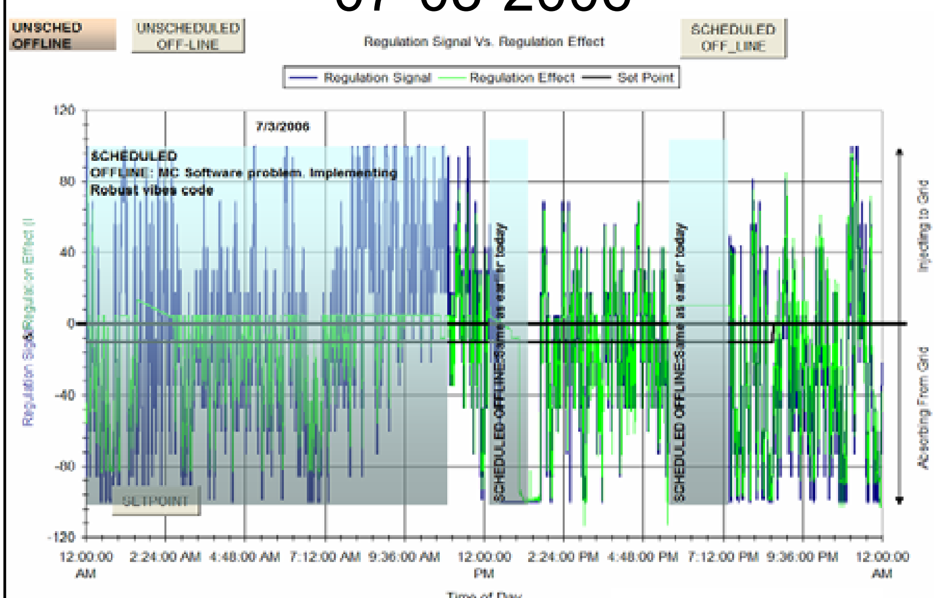

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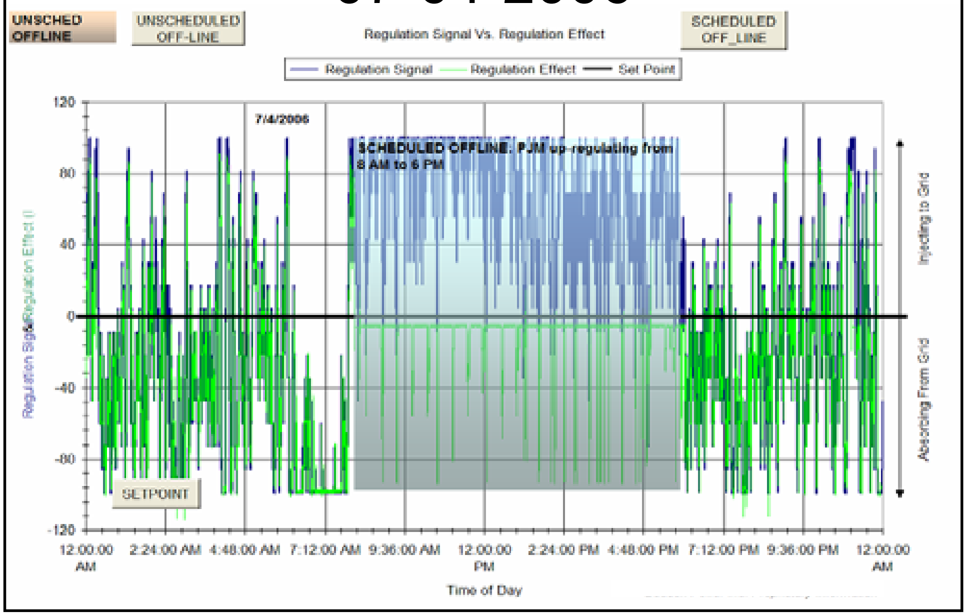

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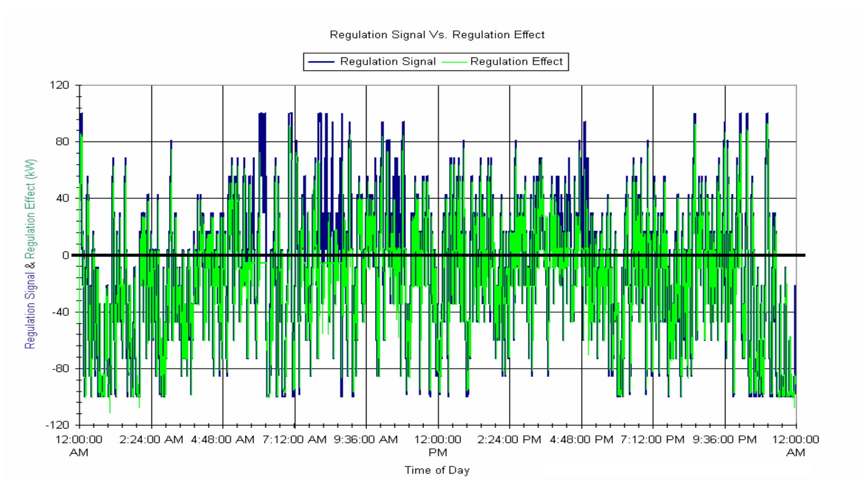

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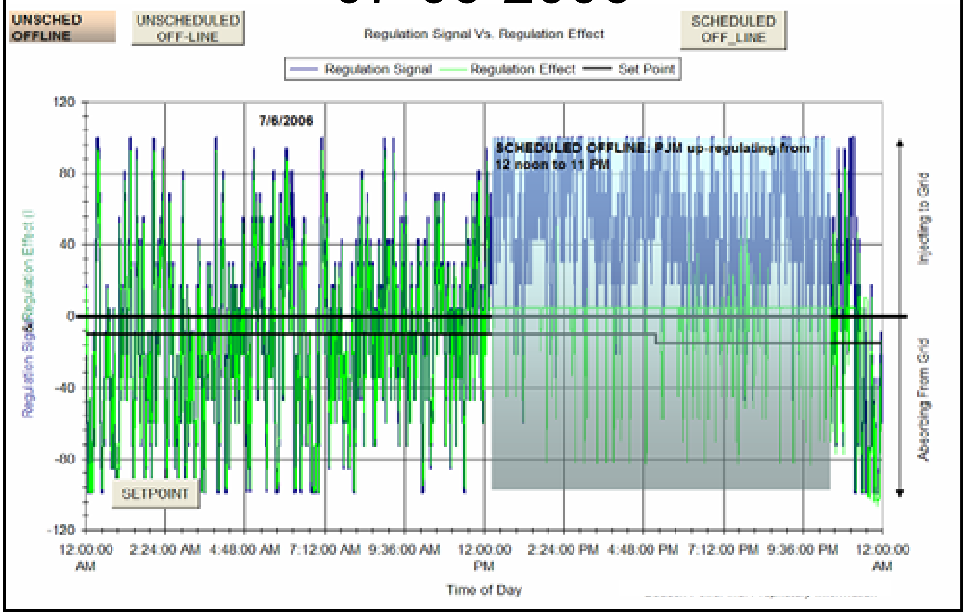

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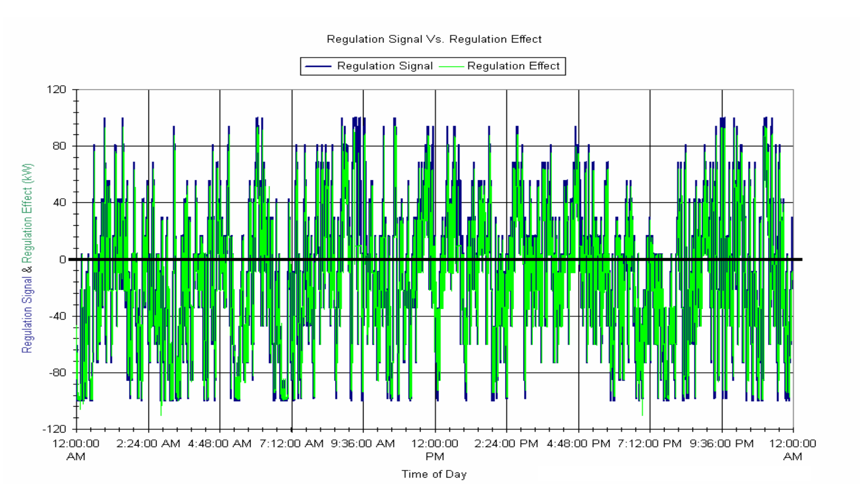

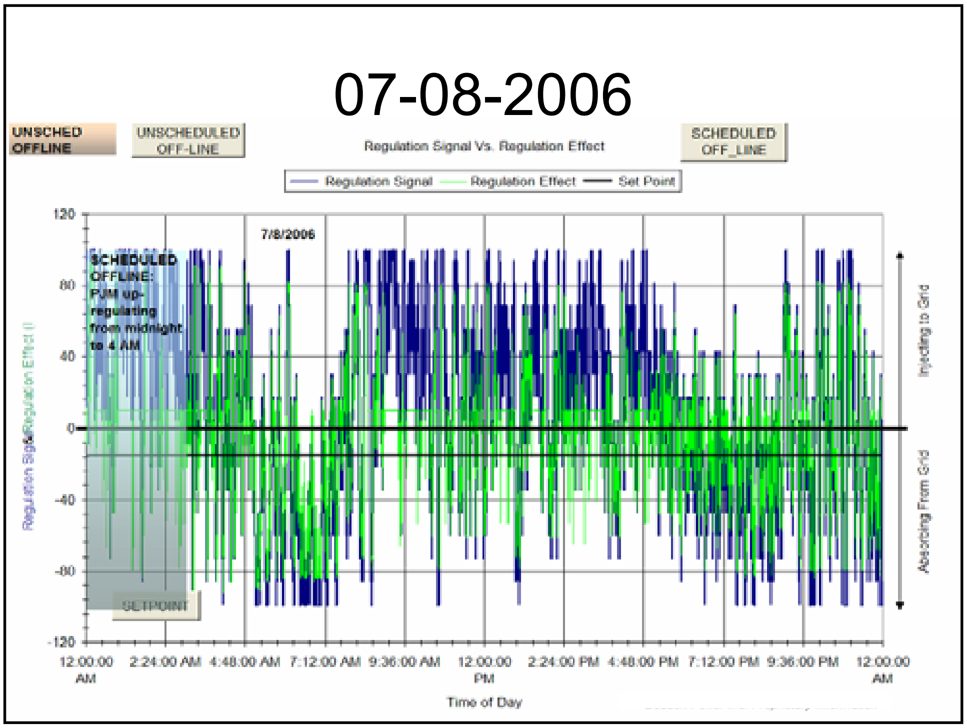
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UNSCHEDULED OFF-LINE
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Regulation Signal
Regulation Effect
Set Point
7/8/2006
SCHEDULED OFFLINE: PJM up-regulating from midnight to 4 AM
SETPOINT
Injecting to Grid
Absorbing From Grid
Time of Day
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80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
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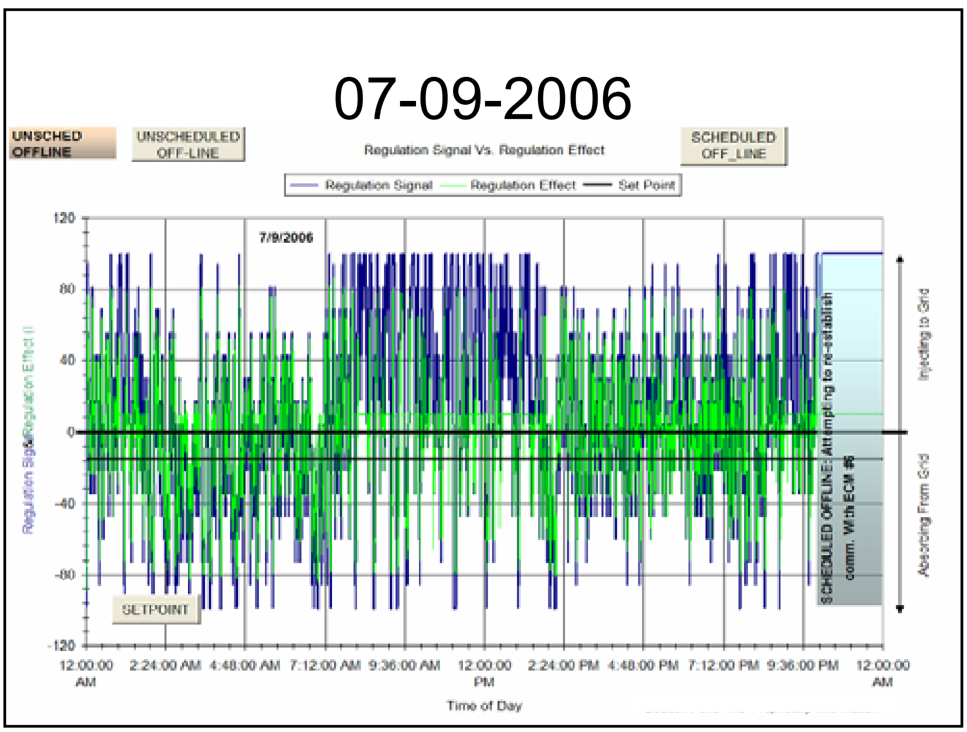
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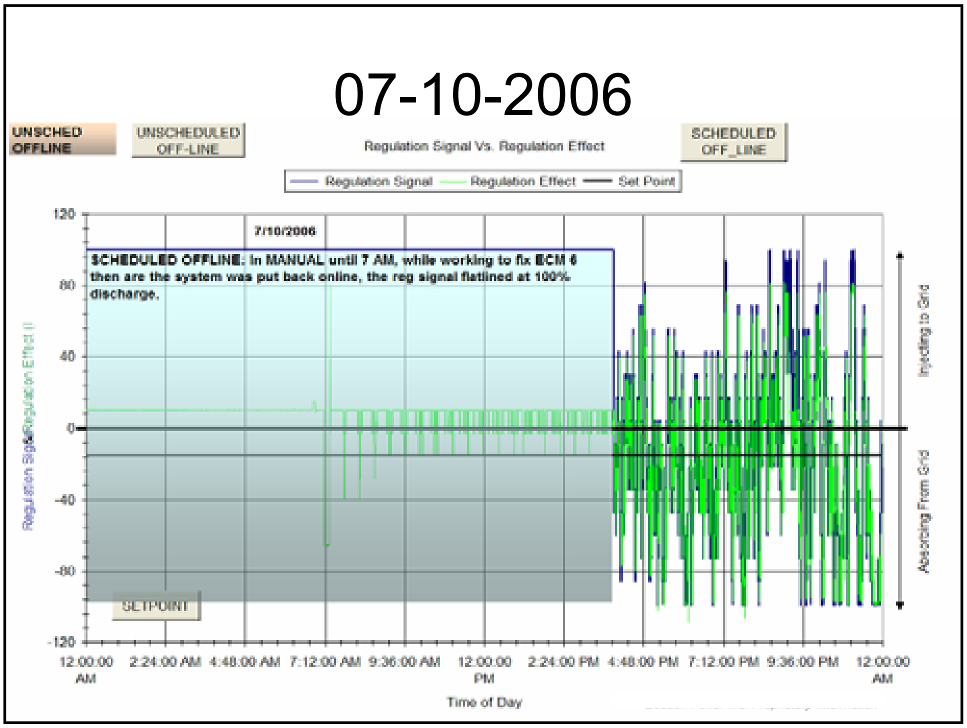
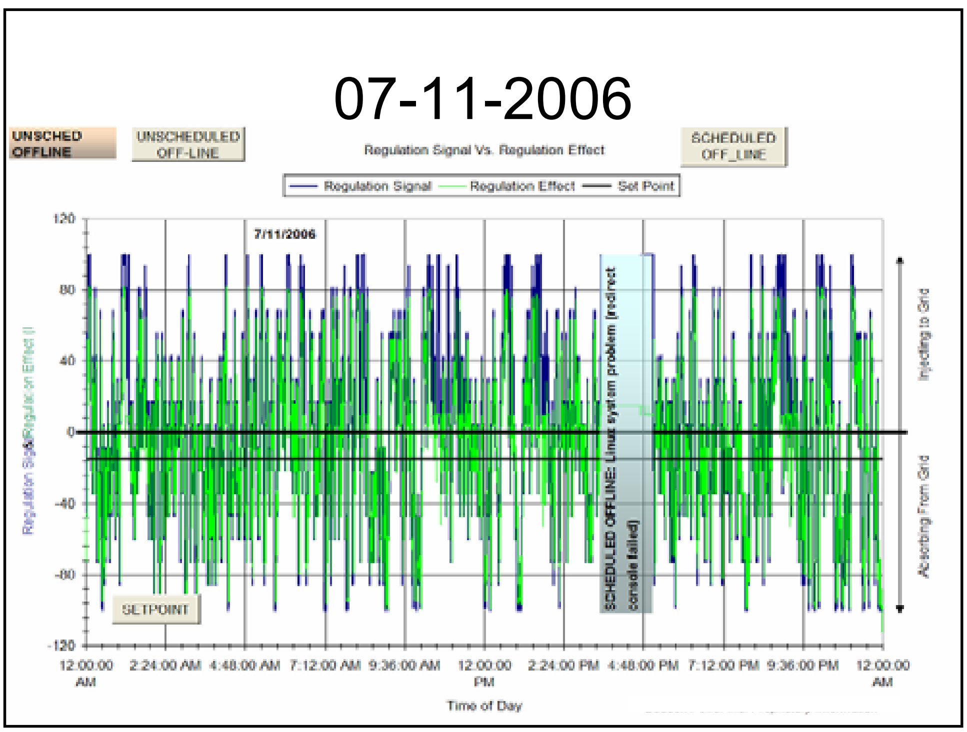
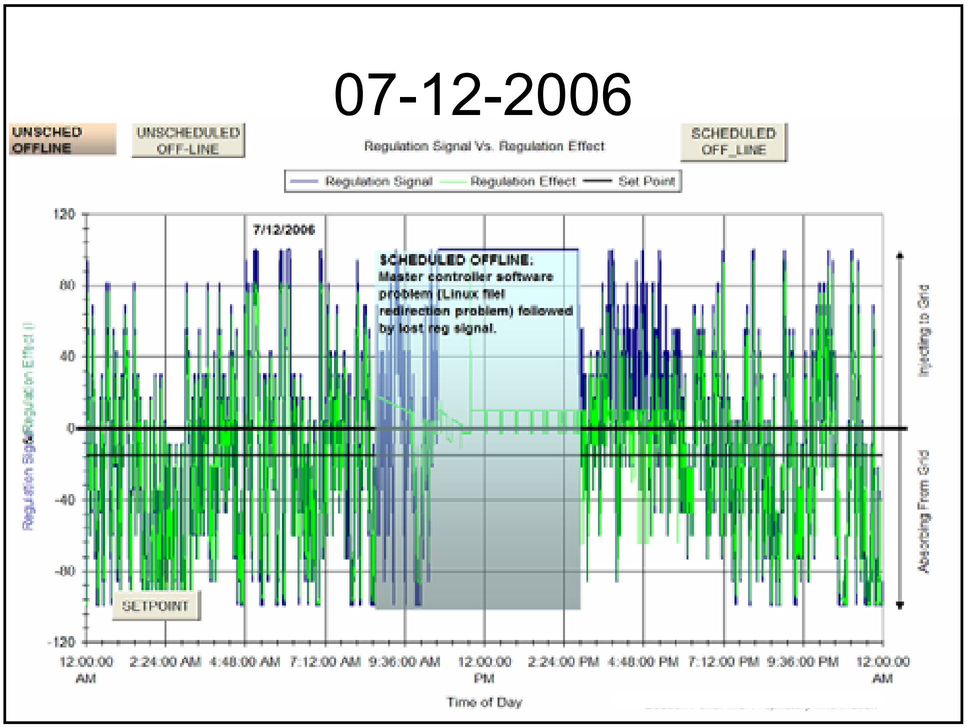
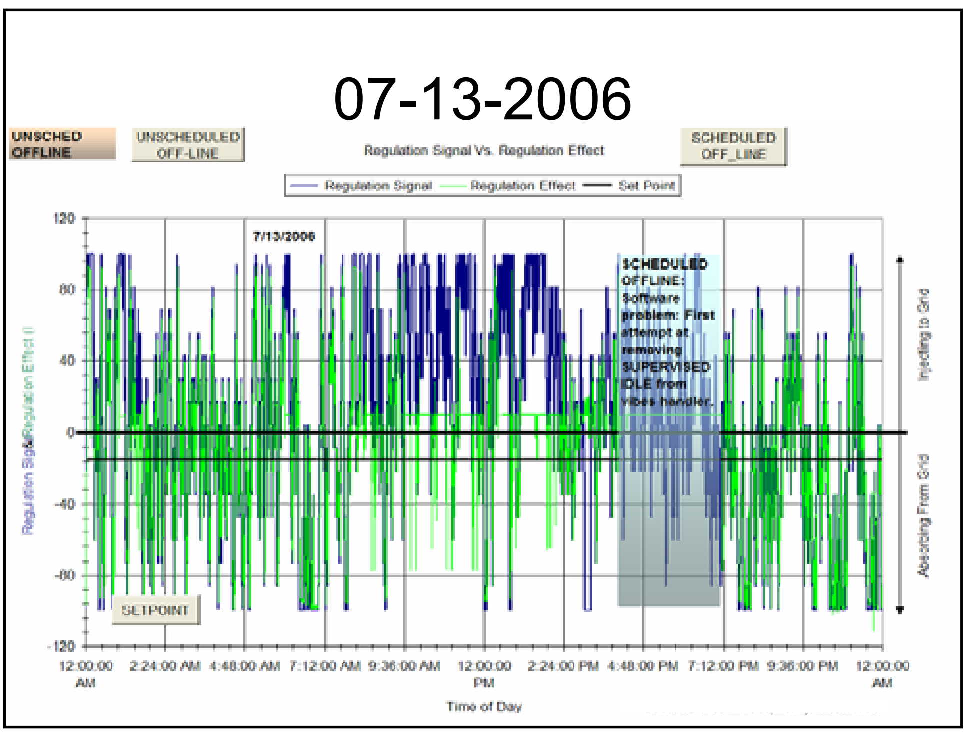
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
7/9/2006
SCHEDULED OFFLINE: Attempting to re-establish comm. With ECM #6
SETPOINT
Injecting to Grid
Absorbing From Grid
Time of Day
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM

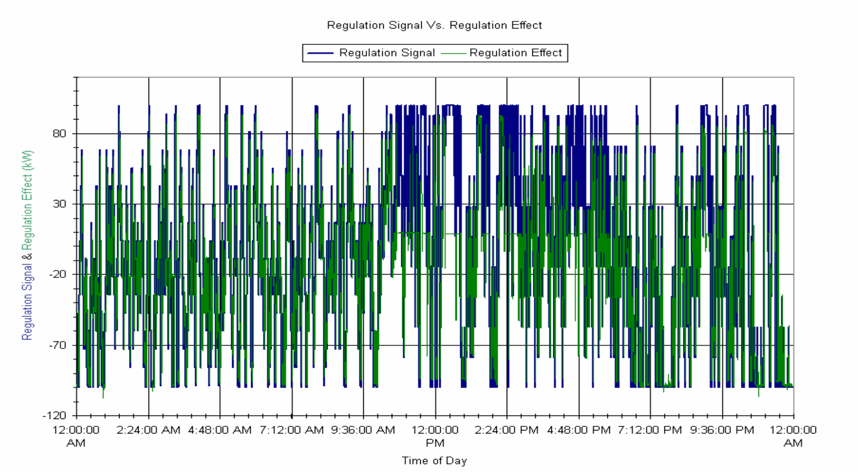

07-10-2006
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
7/10/2006
SCHEDULED OFFLINE: In MANUAL until 7 AM, while working to fix ECM 6 then are the system was put back online, the reg signal flatlined at 100% discharge.
SETPOINT
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day


07-11-2006
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
7/11/2006
SCHEDULED OFFLINE: Linux system problem (redirect console failed)
SETPOINT
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day

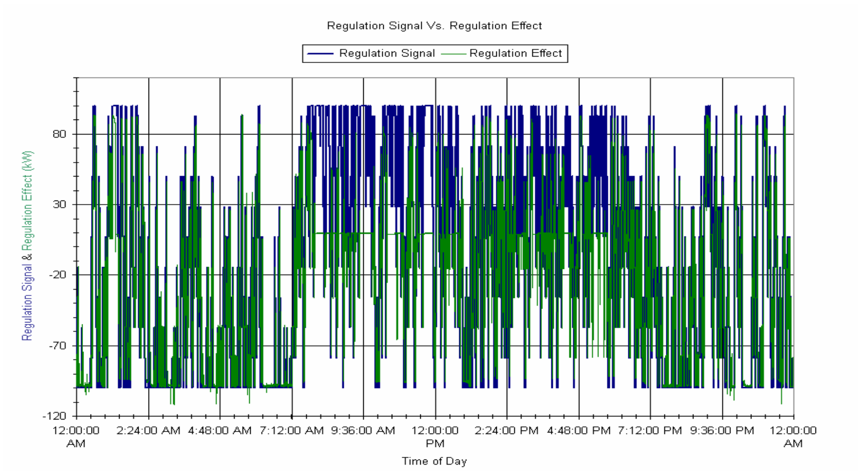

07-12-2006
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
7/12/2006
SCHEDULED OFFLINE: Master controller software problem (Linux file\ redirection problem) followed by lost reg signal.
SETPOINT
Injecting to Grid
Absorbing From Grid
Time of Day


07-13-2006
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
7/13/2006
SCHEDULED OFFLINE: Software problem: First attempt at removing SUPERVISED IDLE from vibes handler.
SETPOINT
Injecting to Grid
Absorbing From Grid
Time of Day

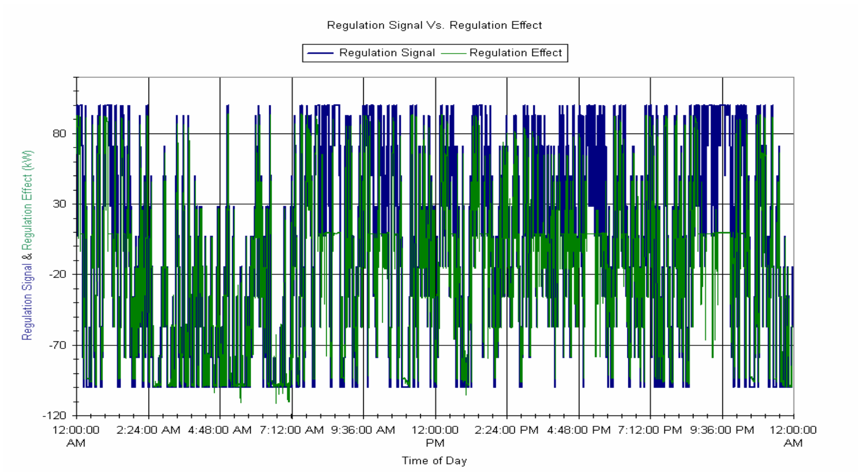
07-14-2006



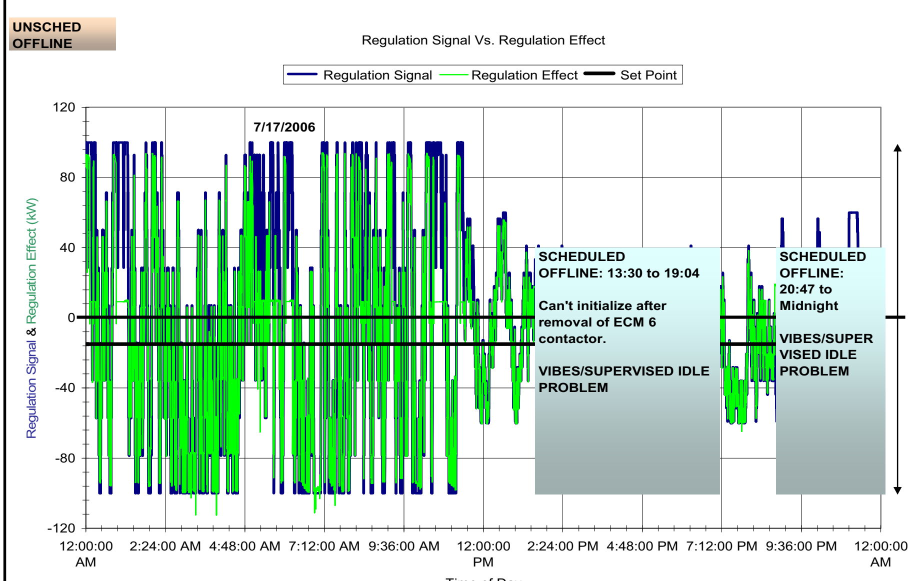
07-15-2006



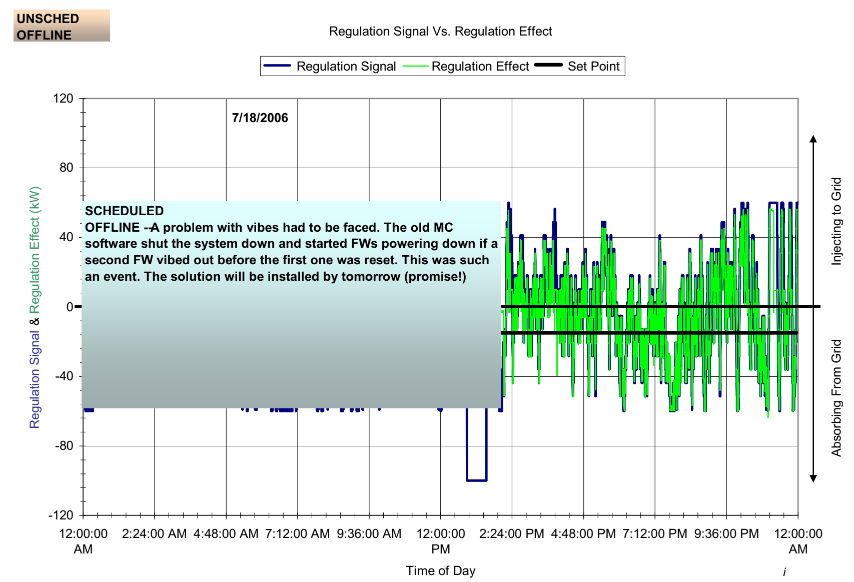
07-16-2006



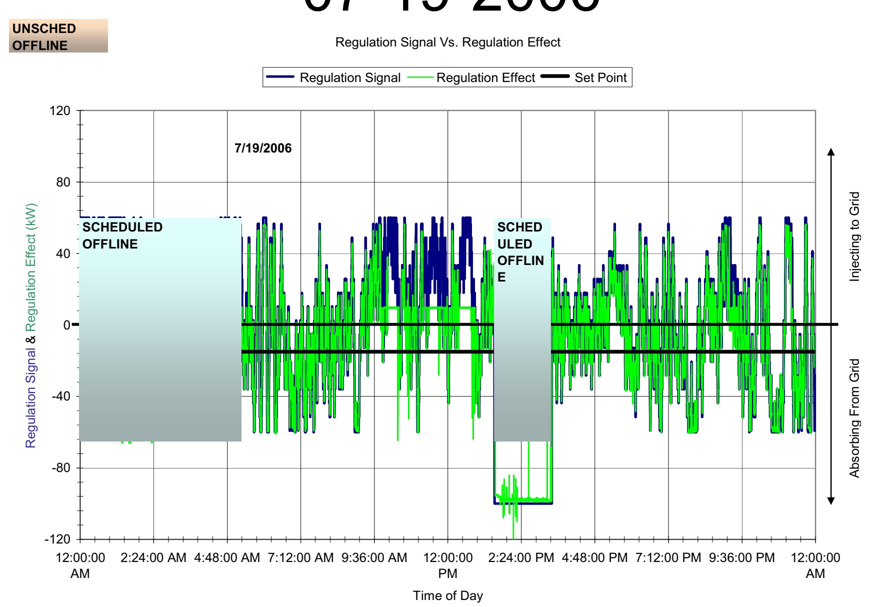
07-17-2006

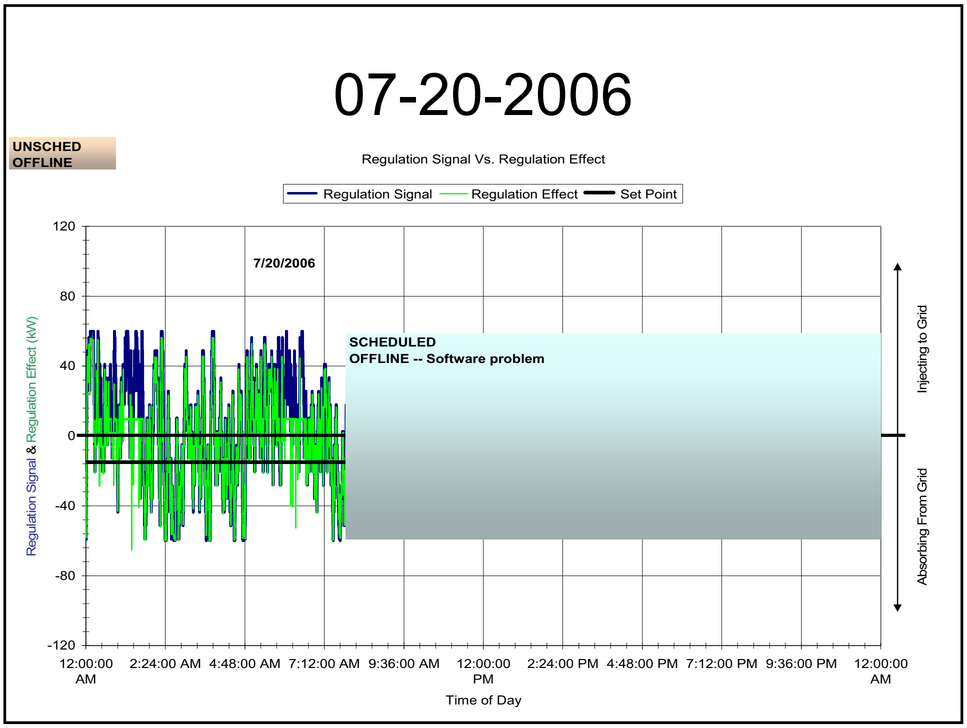


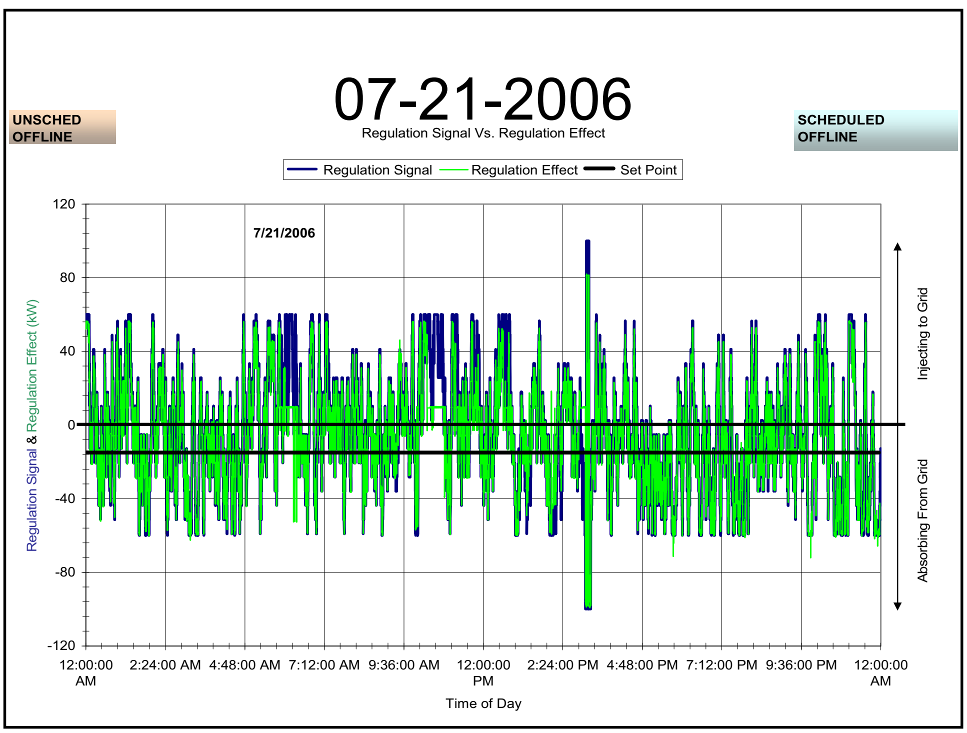
07-18-2006

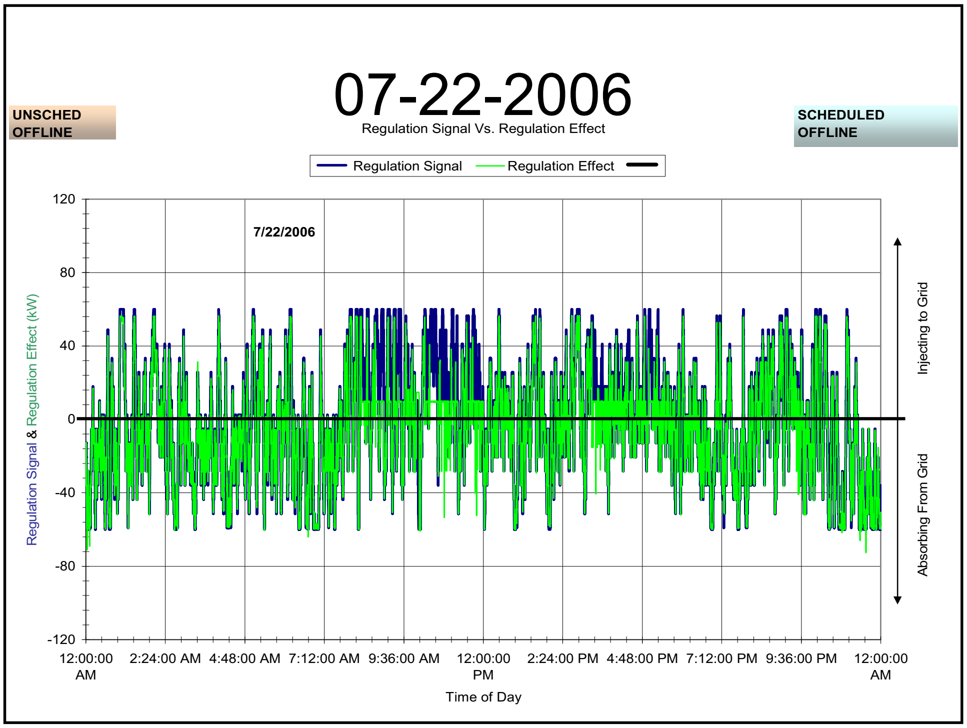


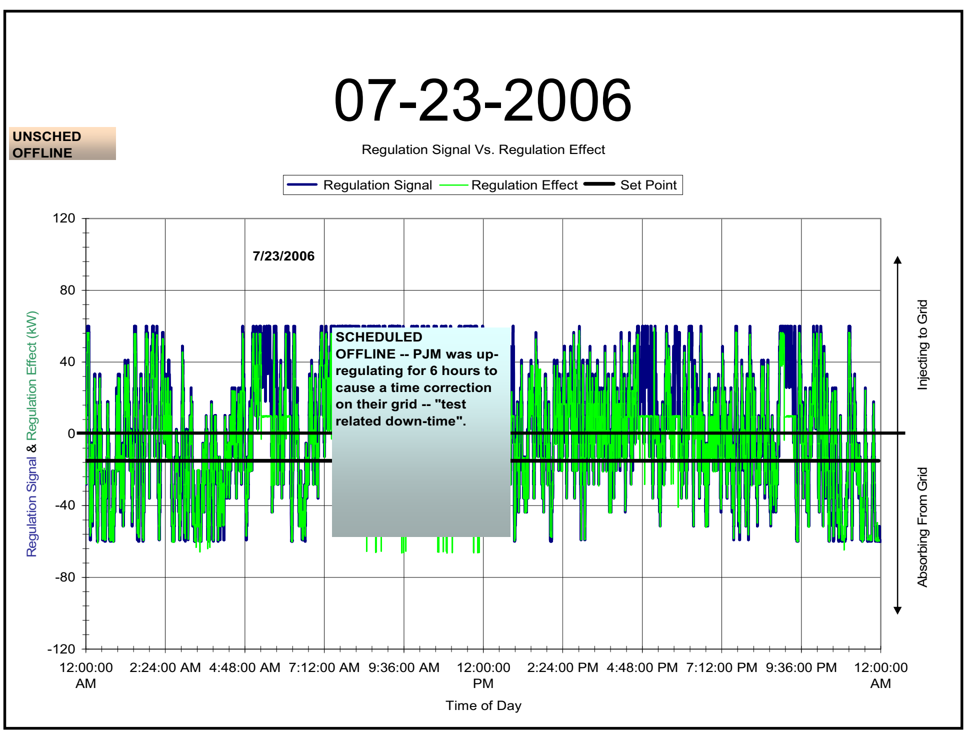
07-19-2006

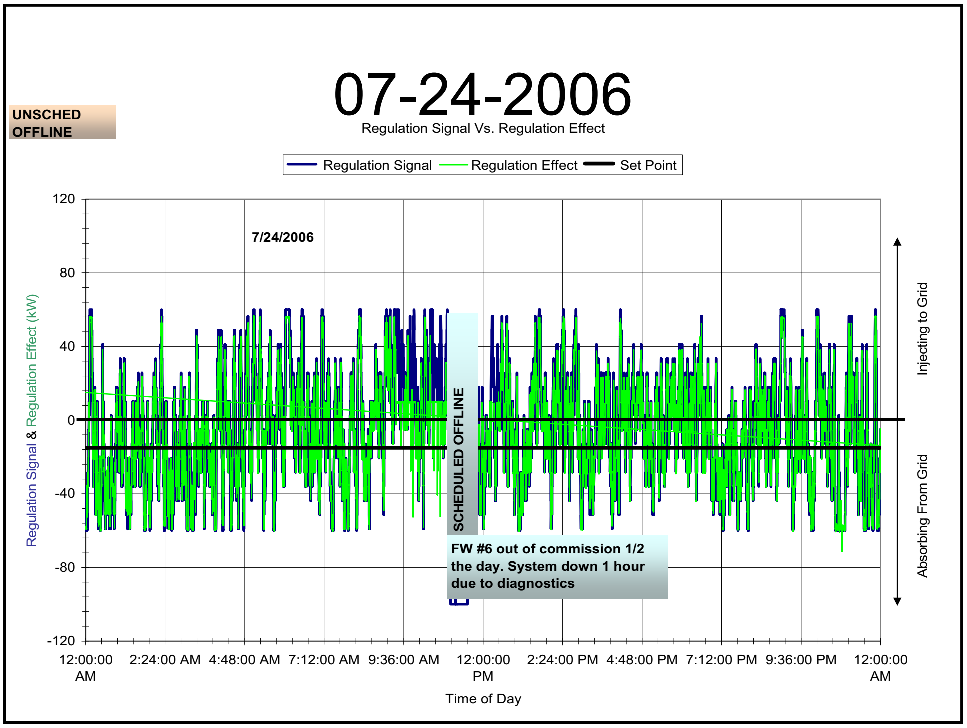


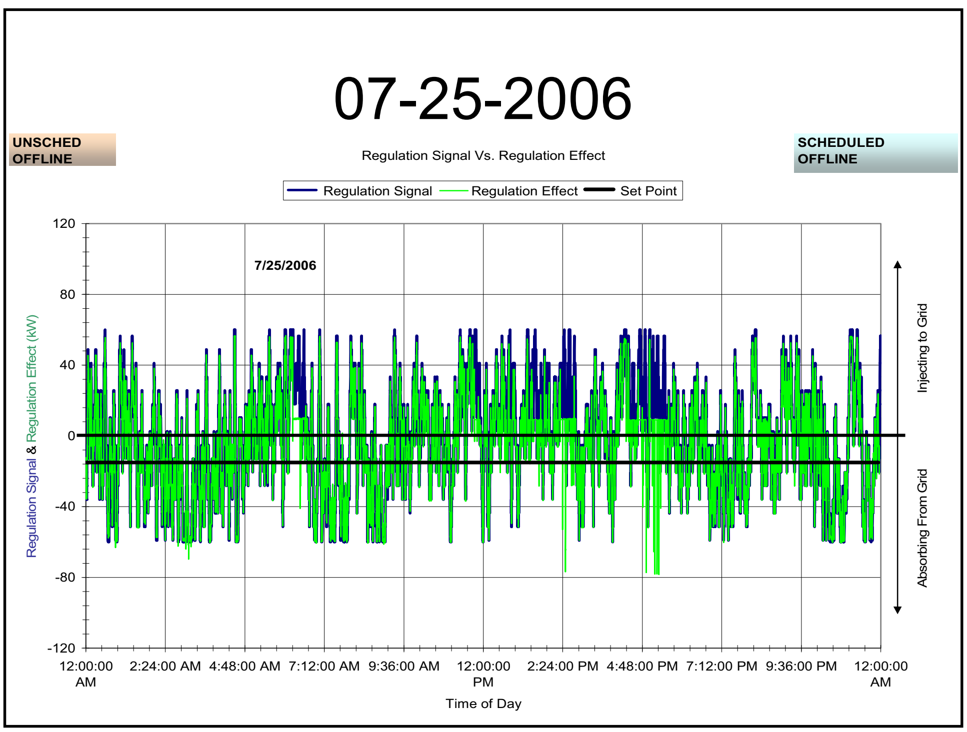

07-20-2006
UNSCHED
OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
7/20/2006
SCHEDULED
OFFLINE -- Software problem
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day


07-21-2006
UNSCHED
OFFLINE
SCHEDULED
OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
7/21/2006
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day

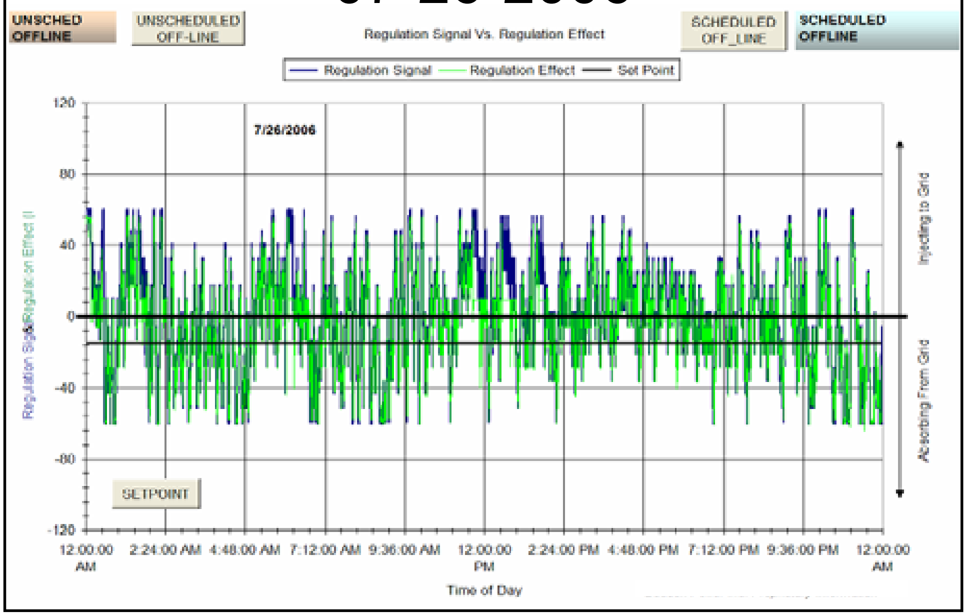

07-22-2006
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
7/22/2006
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day


07-23-2006
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
Regulation Signal
Regulation Effect
Set Point
7/23/2006
SCHEDULED OFFLINE -- PJM was up-regulating for 6 hours to cause a time correction on their grid -- "test related down-time".
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day

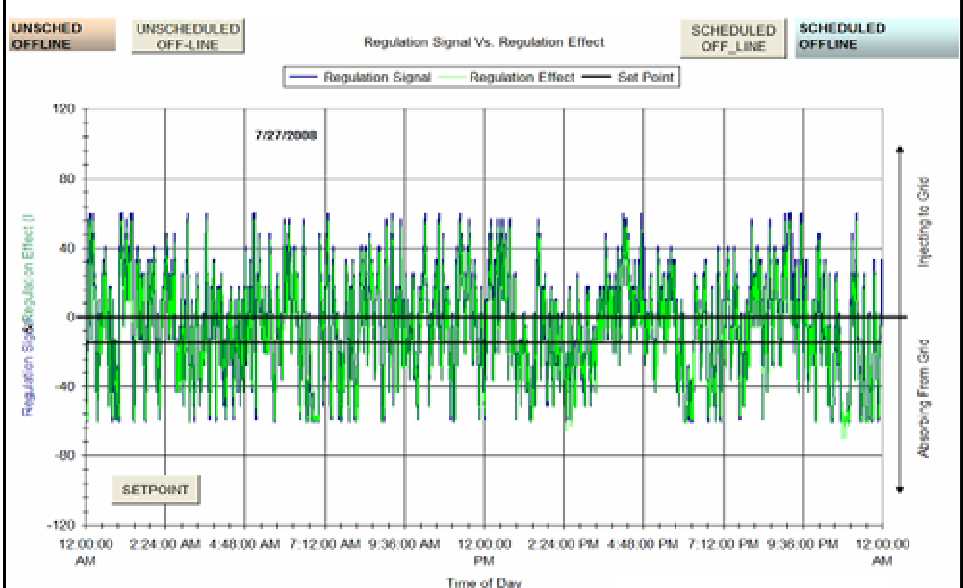

07-24-2006
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
Regulation Signal
Regulation Effect
Set Point
7/24/2006
SCHEDULED OFFLINE
FW #6 out of commission 1/2 the day. System down 1 hour due to diagnostics
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day

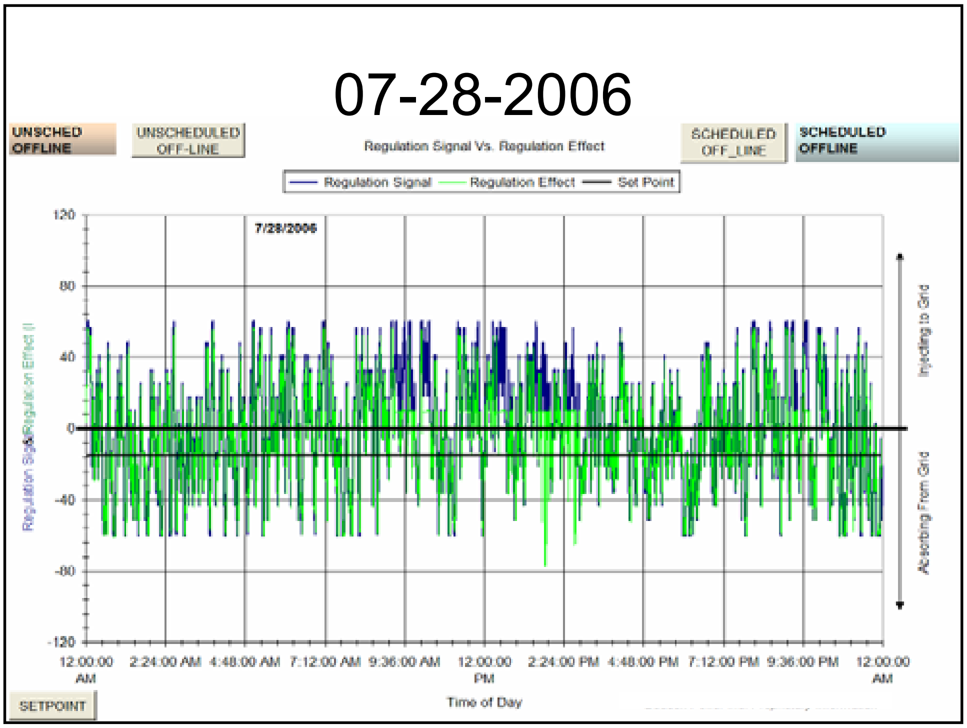

07-25-2006
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
7/25/2006
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day

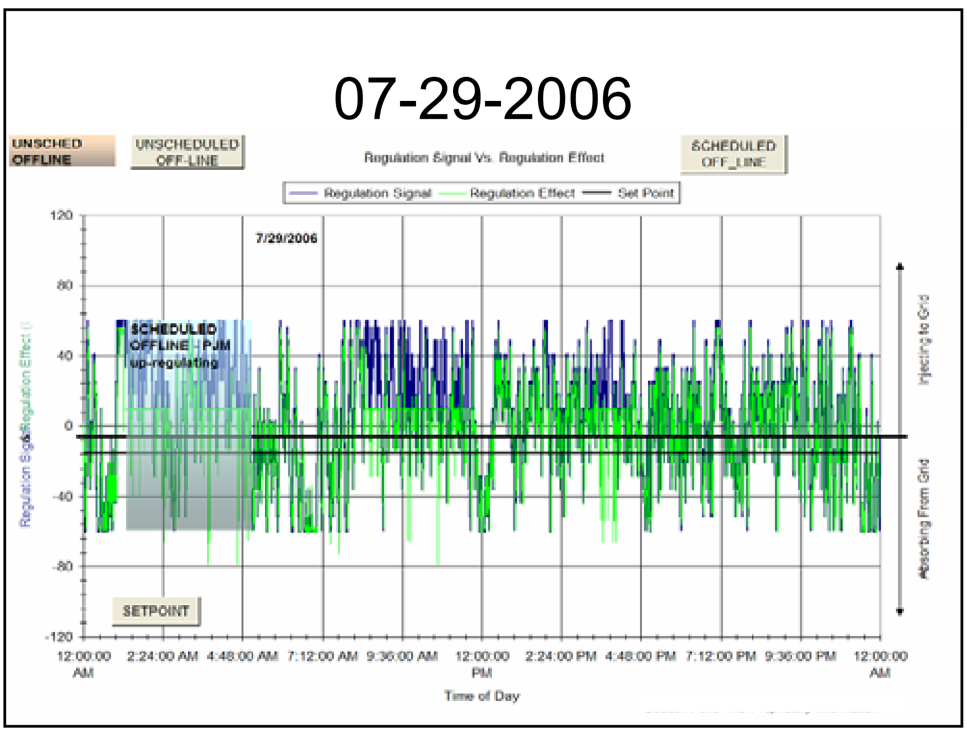
07-26-2006



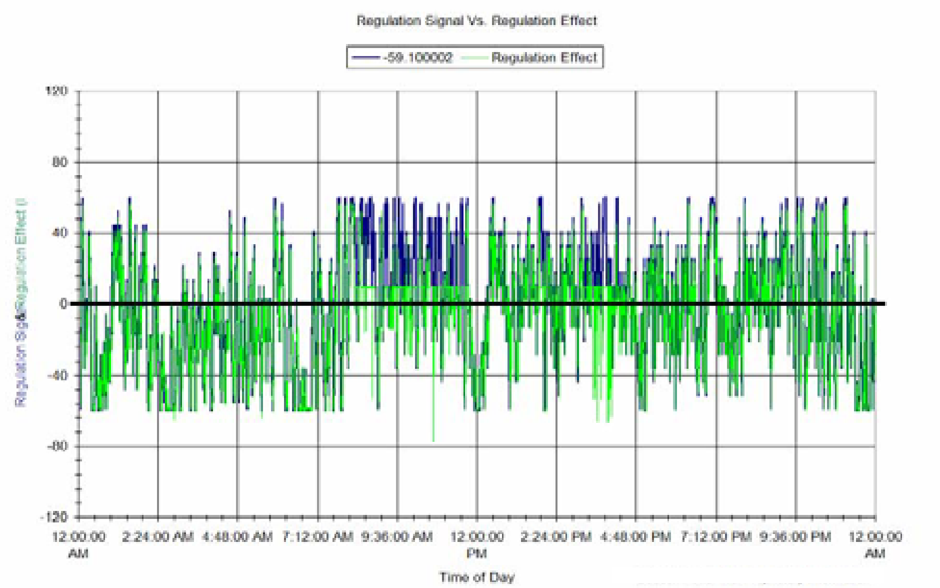
07-27-2006



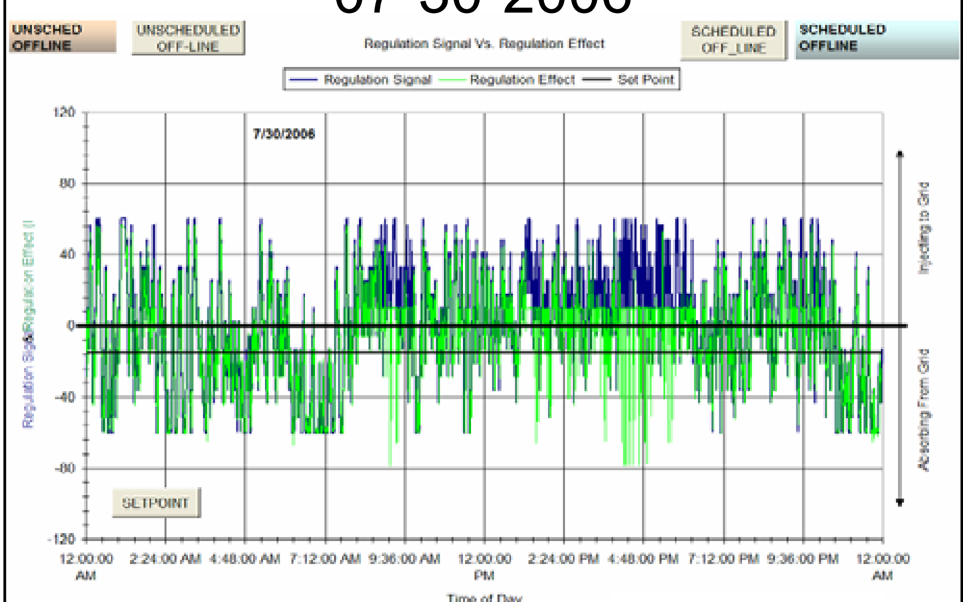

07-28-2006
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
7/28/2006
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
SETPOINT


07-29-2006
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
7/29/2006
SCHEDULED OFFLINE - PJM up-regulating
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
SETPOINT
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day

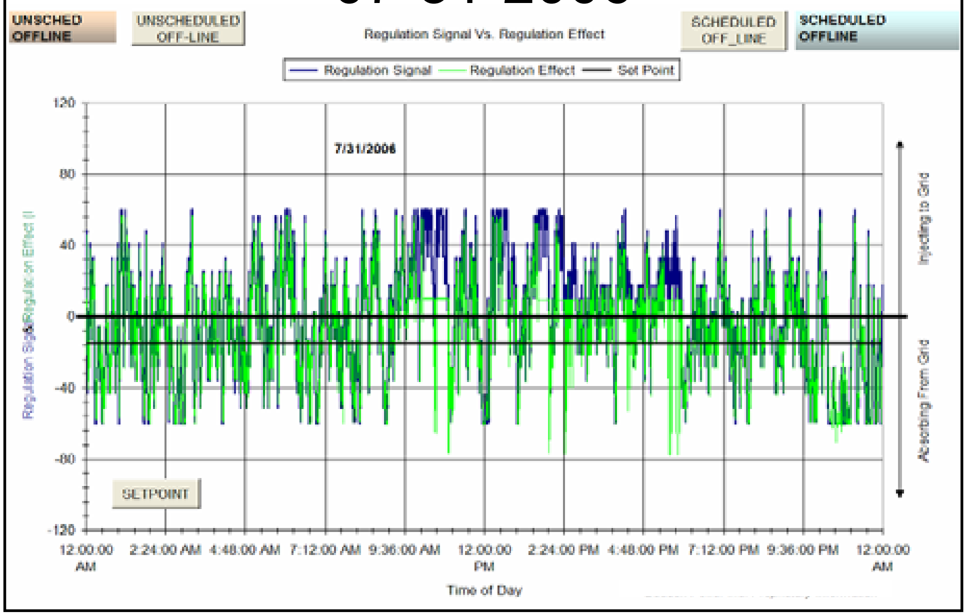
Rerun of 7/29/06



07-30-2006

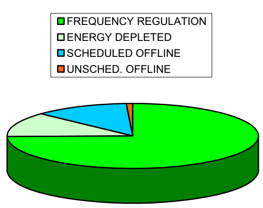


07-31-2006



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

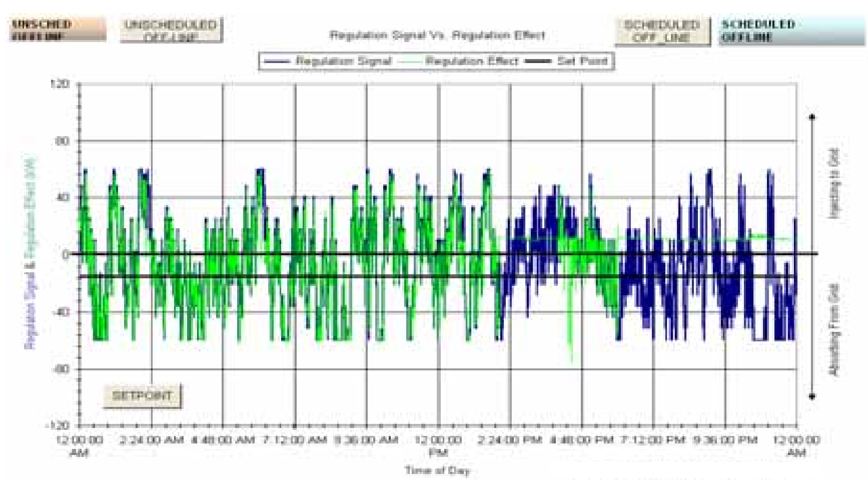
		Percent	Hours
DAILY SUMMARY	FREQUENCY REGULATION	75%	17.9
	ENERGY DEPLETED	12%	3.0
	SCHEDULED OFFLINE	12%	2.9
	UNSCHED. OFFLINE	1%	0.2
	Total	100%	24.0
ON-LINE PERFORMANCE	Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs	84.9%	
	Deviation Excluding Depleted Time	3.6%	
	Deviation Including Depleted Time	10.4%	



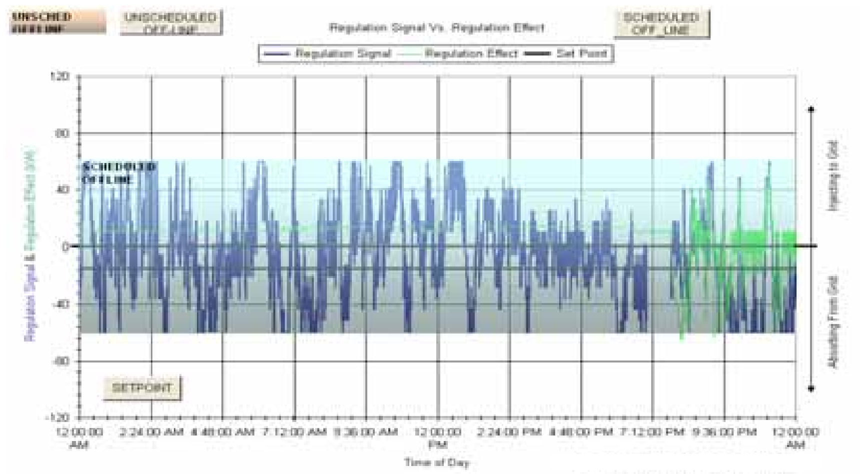
DAILY SUMMARY

August, 2006 NYSERDA SEM Performance Summary													
Date	Freq Reg	Energy Depleted	Total Online Hrs	Offline Unsched	Offline Sched	Avail	Deviation	Deviation w/ depletion	Max KW	Setpoint KW	Cutoff Speed RPM	Max FW's	Comment
1-Aug	14.92	0.48	15.40	1.99	6.61	85.80%	2.27%	3.70%	60kW	15000	17500	7	Motor over temp, Chiller failure.
2-Aug	0.00	0.00	0.00	0.00	24.00	100.00%	3.64%	10.43%	60kW	15000	17500	7	Repaired Chiller, problems with FW1&7 comm interface.
3-Aug	20.13	2.90	23.04	0.97	0.00	83.89%	10.73%	15.53%	66kW	15000	17500	7	Solved ID problems.
4-Aug	15.94	7.13	23.08	0.92	0.00	66.43%	2.20%	17.91%	60kW	15000	17500	7	11 hours of up-regulation due to "time correction"
5-Aug	18.92	5.08	24.00	0.00	0.00	78.83%	2.15%	13.59%	60kW	15000	17500	7	
6-Aug	17.76	6.23	23.99	0.01	0.00	74.01%	2.19%	19.37%	60kW	15000	17500	7	5 hours of up-regulation due to "time correction (see figure)
7-Aug	15.46	1.19	16.64	0.03	7.32	92.69%	2.33%	5.87%	60kW	15000	17500	7	Regulation signal froze at 12.8 kW for 18 hrs
8-Aug	22.77	1.19	23.95	0.05	0.00	94.86%	1.81%	4.30%	60kW	15000	17500	7	Regulation signal froze at 12.8 kW for 18 hrs
9-Aug	22.78	1.21	23.99	0.01	0.00	94.93%	2.05%	4.23%	60kW	15000	17500	7	
10-Aug	21.98	2.02	24.00	0.00	0.00	91.60%	2.06%	6.44%	60kW	15000	17500	7	
11-Aug	23.05	0.94	23.99	0.01	0.00	96.04%	2.10%	3.75%	60 kW	15000	17500	7	
12-Aug	17.95	6.04	23.99	0.01	0.00	74.81%	2.04%	16.20%	60 kW	15000	17500	7	6 hours of up-regulation due to "time correction (see figure)
13-Aug	15.86	3.37	19.23	0.01	4.76	82.42%	1.45%	6.72%	60-80	15000	17500	7	From 8 AM to 2 PM freq is very low and caused energy depletion. Regulation signal stuck
14-Aug	12.38	0.68	13.06	1.00	9.94	88.03%	2.79%	6.16%	80kW	15000	17500	7	Chiller faulted about 11 hrs today
15-Aug	12.15	1.20	13.35	0.01	10.64	90.94%	9.21%	10.39%	40-60	15000	17500	7	Chiller faulted, then Beckwith trip while in MANUAL
16-Aug	21.69	2.30	23.99	0.01	0.00	90.38%	22.05%	25.05%	60kW	15000	17500	7	9 hrs of up-regulation due to "time correction (see figure)
17-Aug	23.39	0.61	24.00	0.00	0.00	97.47%	9.53%	10.61%	60kW	15000	17500	7	6 hrs of up-regulation (time correction)
18-Aug	21.39	2.53	23.91	0.09	0.00	89.11%	1.87%	7.46%	60kW	15000	17500	7	
19-Aug	21.50	2.51	24.00	0.00	0.00	89.57%	1.92%	7.46%	80kW	15000	17500	7	
20-Aug	20.06	3.85	23.91	0.09	0.00	83.57%	2.27%	9.81%	88kW	15000	17500	7	
21-Aug	14.74	9.26	24.00	0.00	0.00	61.41%	2.37%	20.79%	80kW	15000	17500	6	Similar RS to 26-Aug
22-Aug	15.79	5.50	21.29	0.07	2.64	73.93%	2.13%	15.38%	80kW	15000	17500	6	2.5 hrs of scheduled downtime was pilot error. Went to MANUAL and forgot to cycle back to AUTO (7 hrs of up reg?)
23-Aug	14.12	0.61	14.72	0.01	9.27	95.84%	2.00%	3.74%	80kW	15000	17500	6	System in MANUAL for several hours doing troubleshooting with ECM #2
24-Aug	21.72	1.97	23.69	0.31	0.00	90.50%	1.51%	5.41%	80kW	15000	17500	6	
25-Aug	21.66	2.03	23.69	0.31	0.00	90.24%	1.12%	4.19%	100kW	15000	17500	6	
26-Aug	16.88	7.12	24.00	0.00	0.00	70.33%	1.88%	20.73%	80kW	15000	17500	6	between 8 AM & 2 PM up regulating only
27-Aug	22.01	1.99	24.00	0.00	0.00	91.70%	1.68%	5.59%	80kW	15000	17500	6	
28-Aug	21.60	2.40	24.00	0.00	0.00	90.00%	1.44%	6.04%	80kW	15000	17500	6	
29-Aug	16.96	7.04	24.00	0.00	0.00	70.66%	1.90%	20.54%	80kW	15000	17500	6	between 8 AM & 2 PM up regulating only
30-Aug	22.04	1.97	24.00	0.00	0.00	91.82%	1.49%	5.29%	80kW	15000	17500	6	
31-Aug	8.21	0.42	8.63	1.00	14.37	85.23%	8.54%	10.60%	80kW	15000	17500	6	Flatlined reg signal (early) and MC bug exposed by faulted ECM at end of day carries fault over into tomorrow
Avg	17.93	2.96	20.89	0.22	2.89	84.93%	3.64%	10.43%					

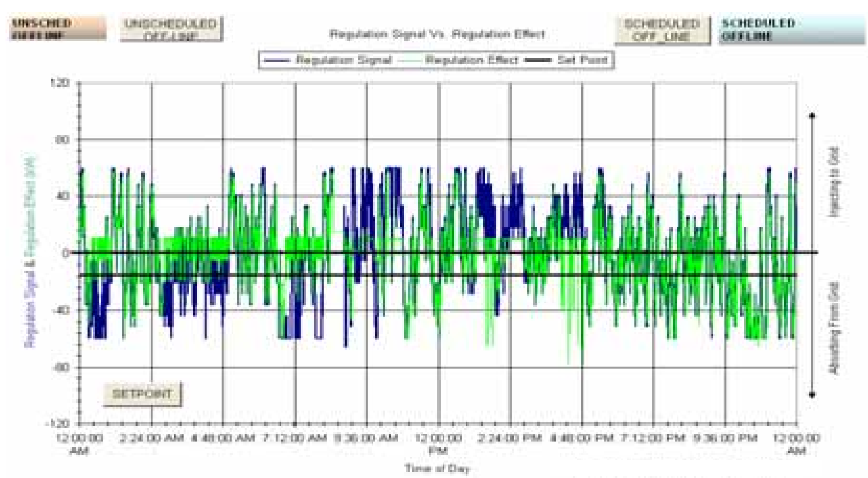
08-01-2006



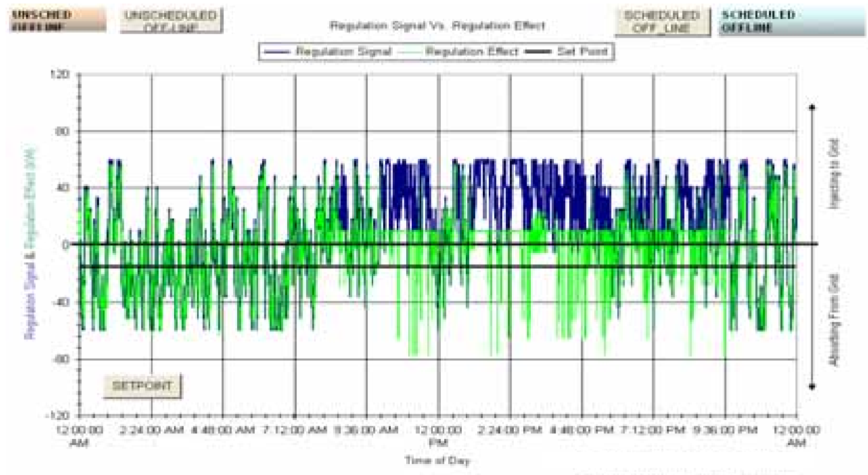
08-02-2006



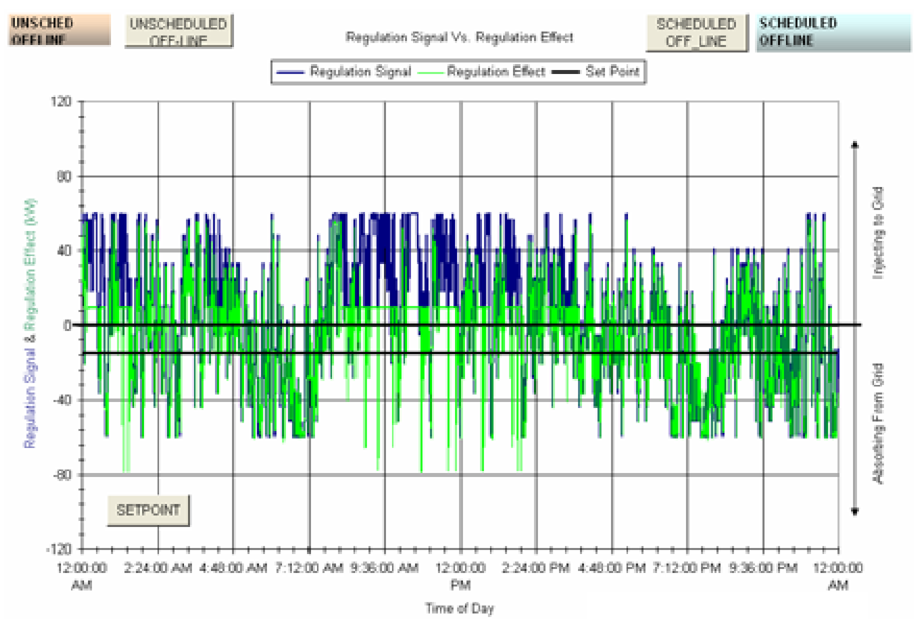
08-03-2006



08-04-2006

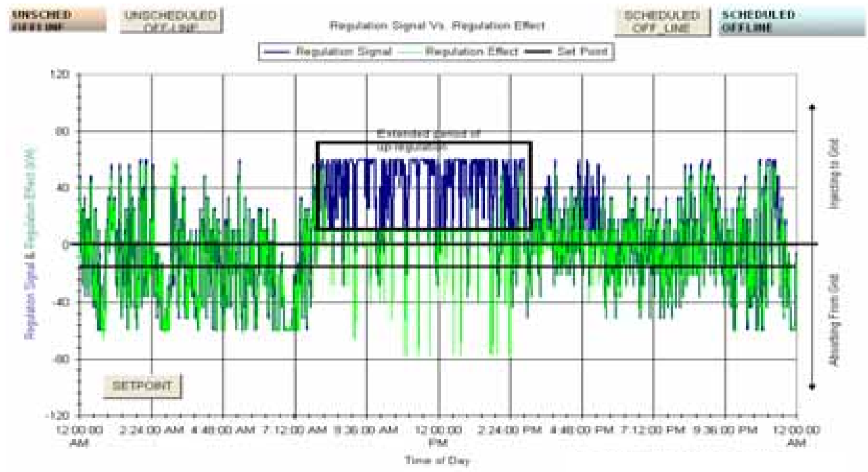


UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
SETPOINT
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day



UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
SETPOINT
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day

08-06-2006



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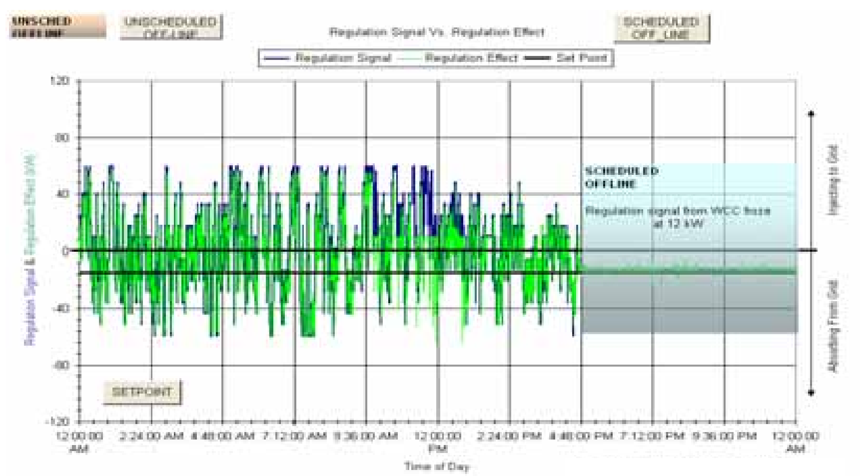

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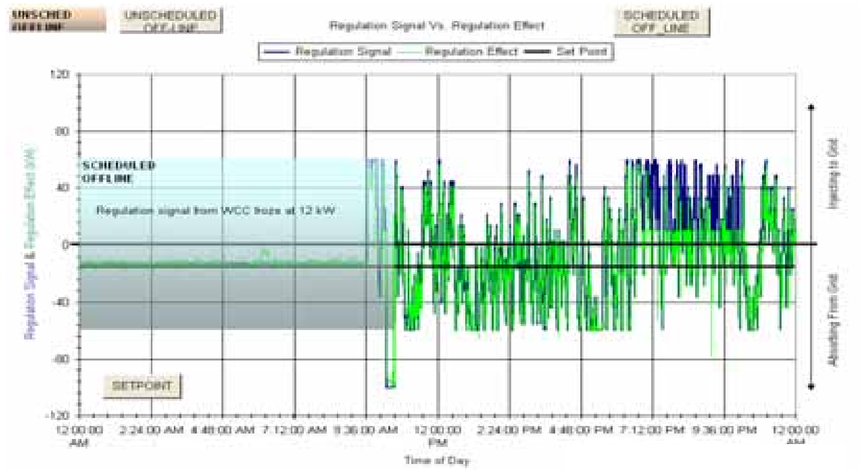

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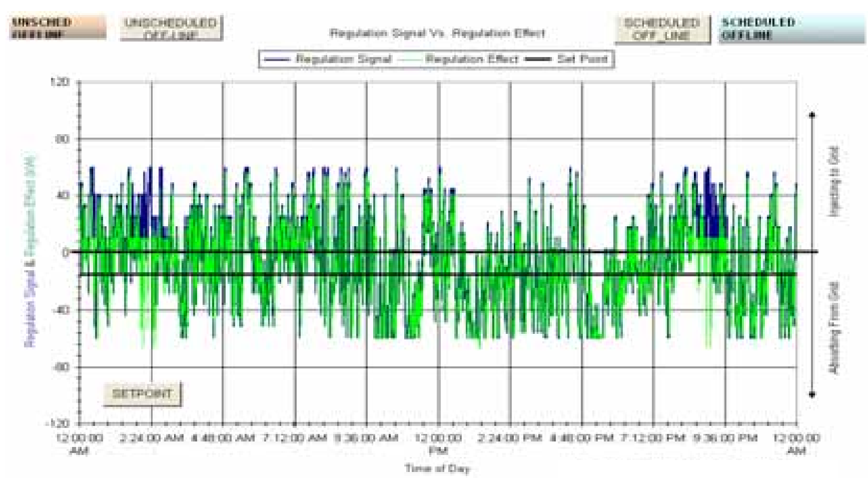

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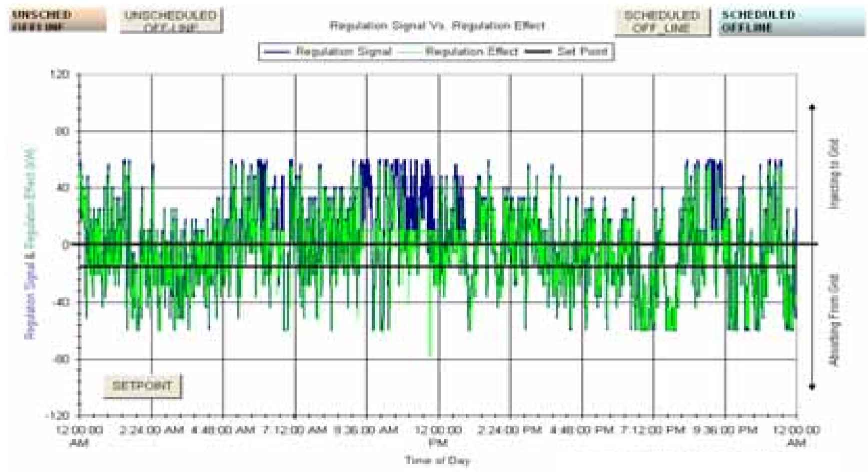

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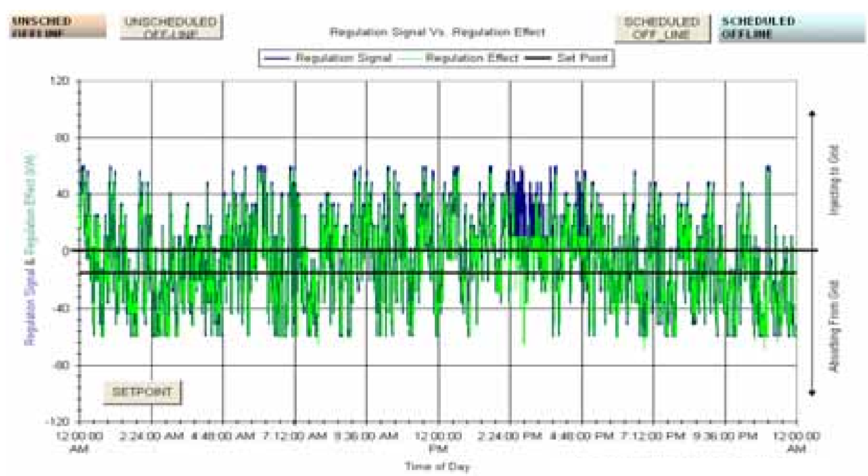

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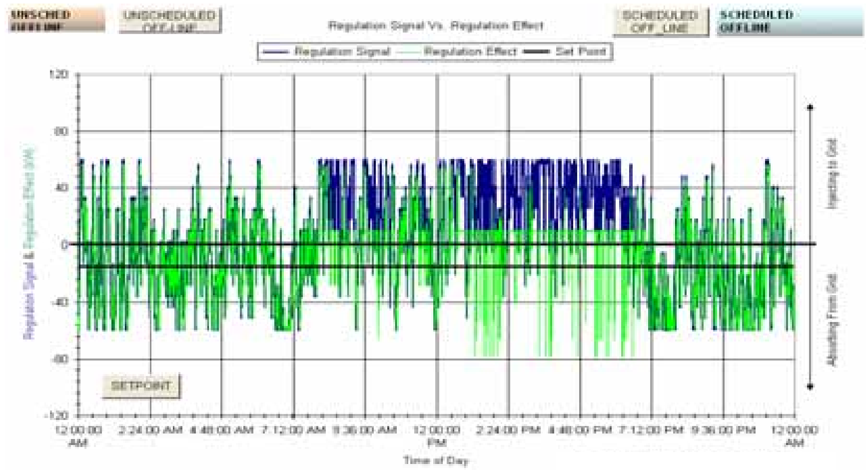

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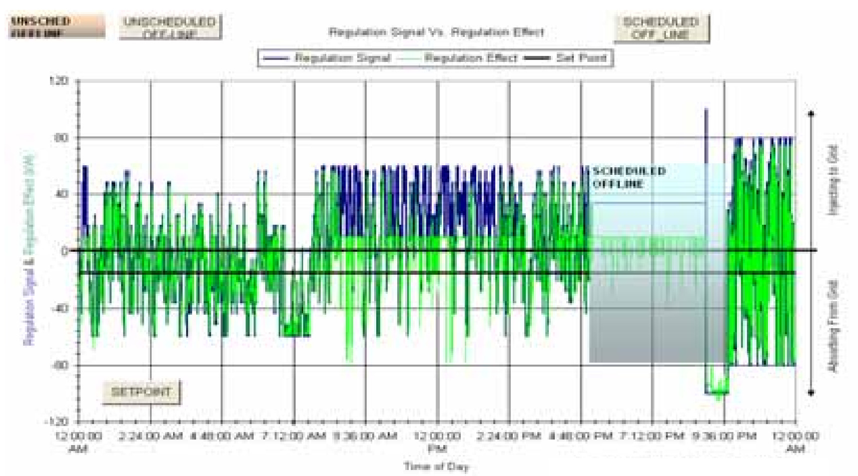

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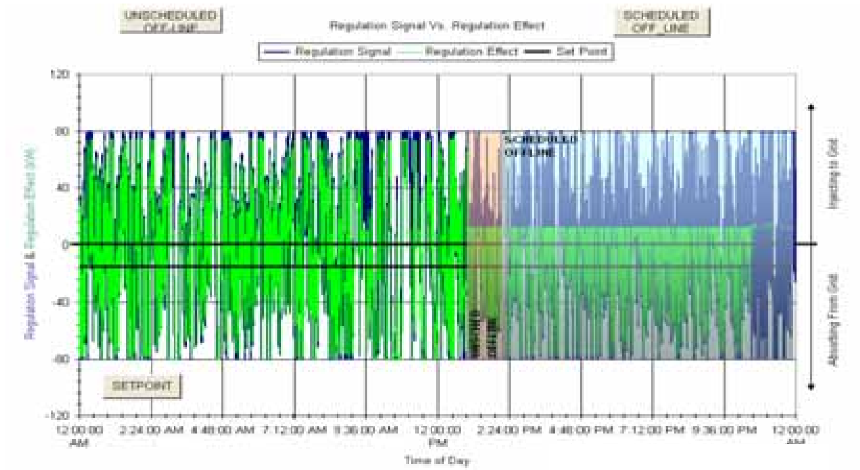

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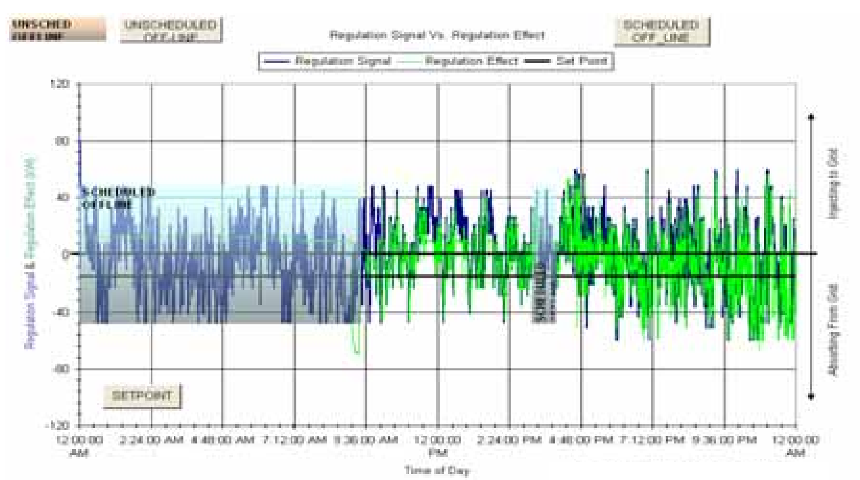

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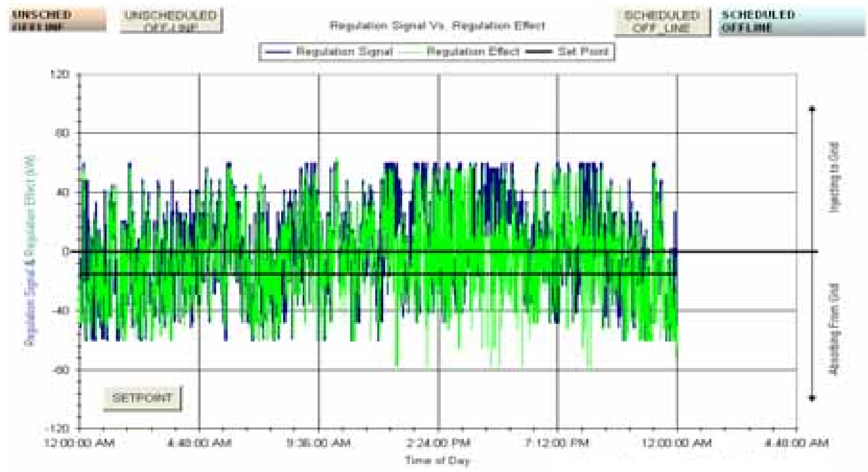

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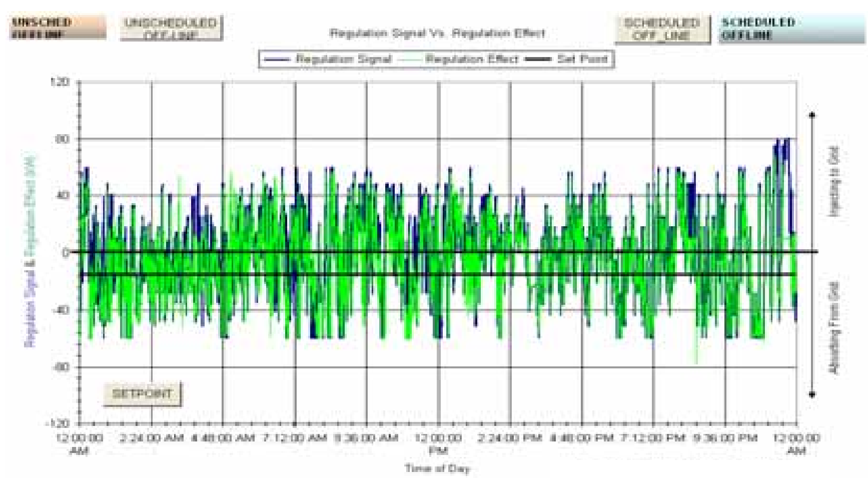

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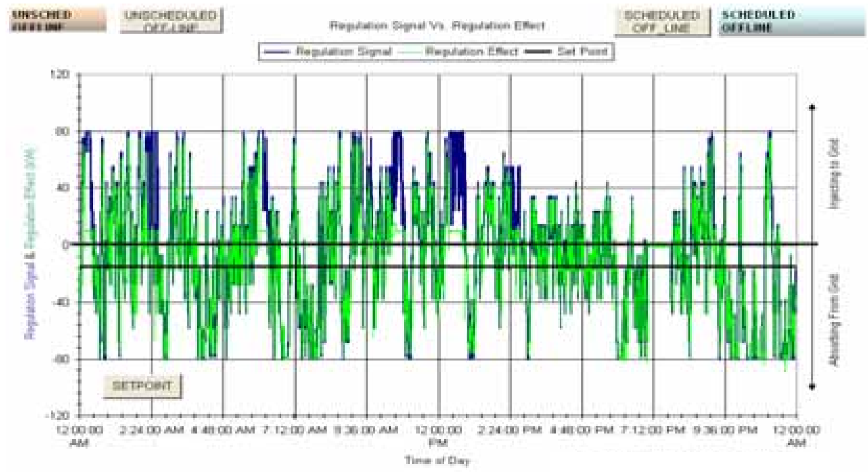

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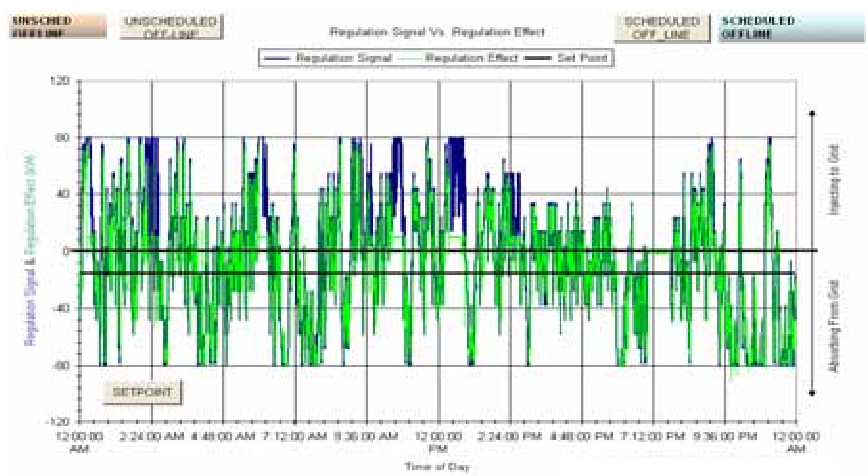

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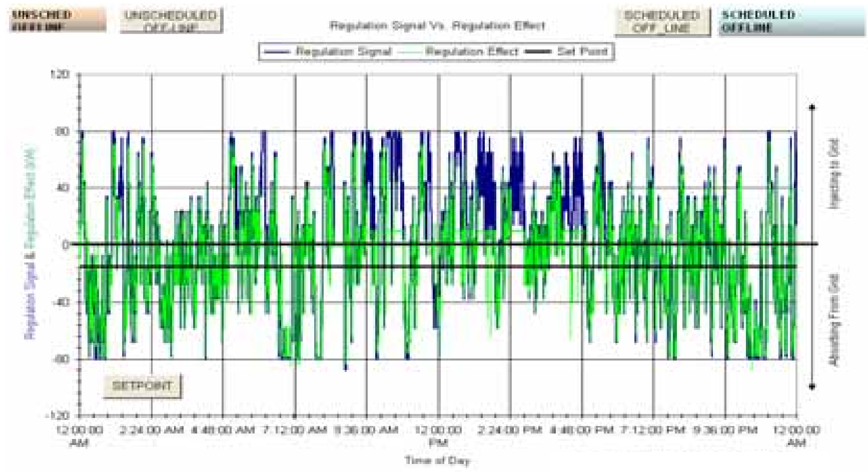

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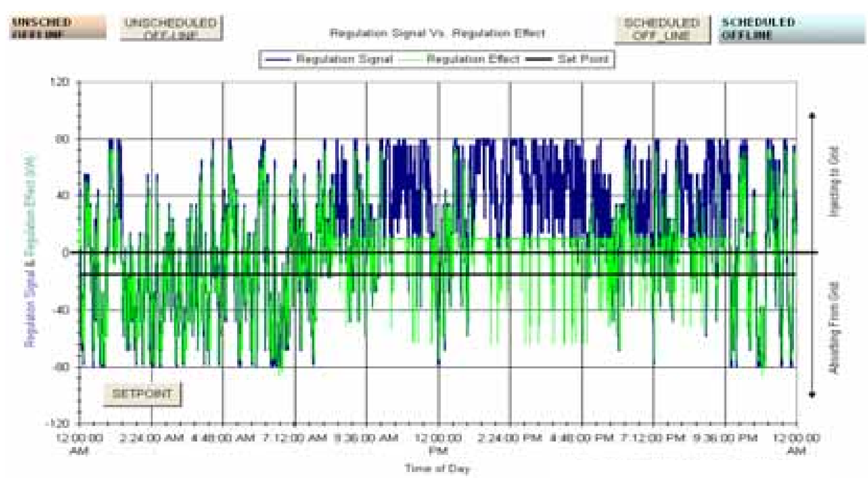

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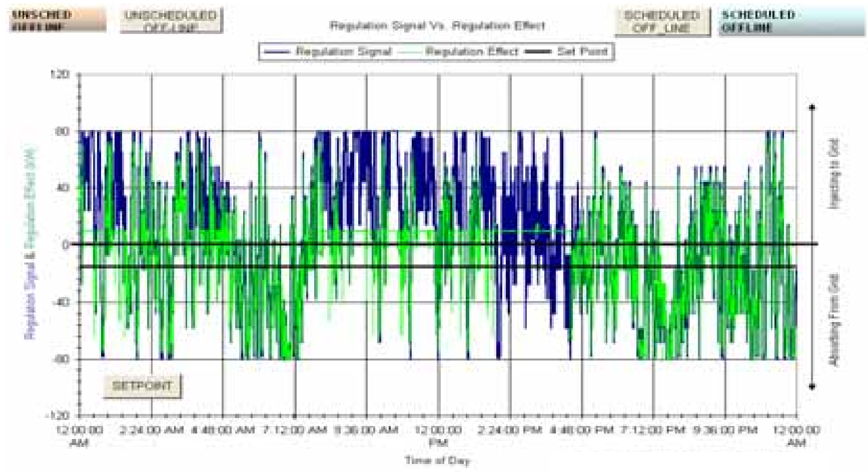

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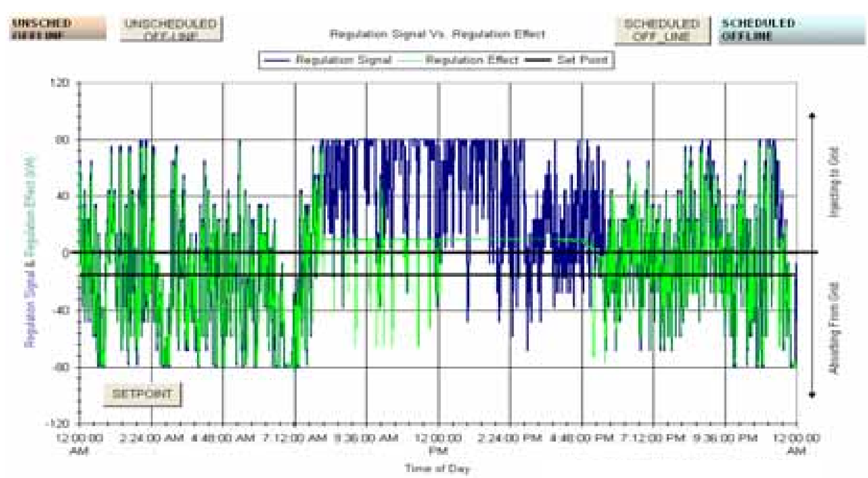

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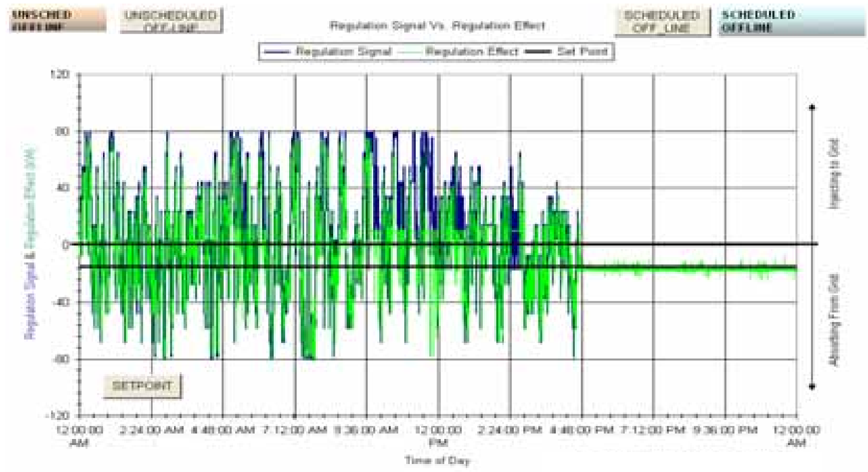

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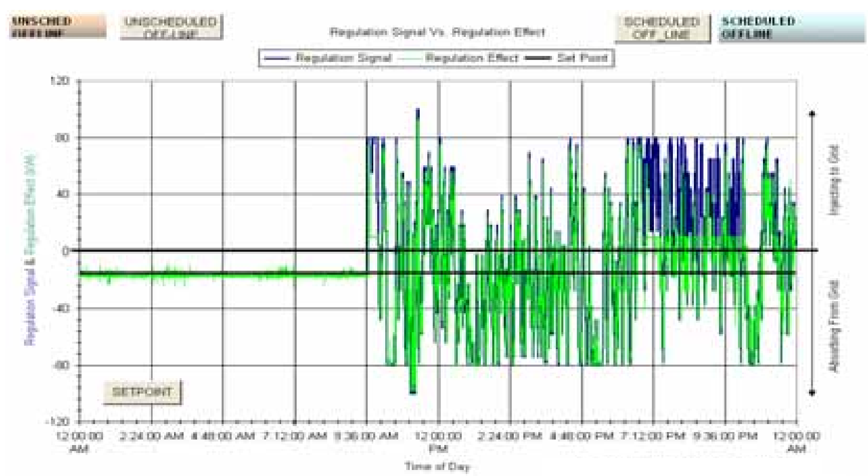

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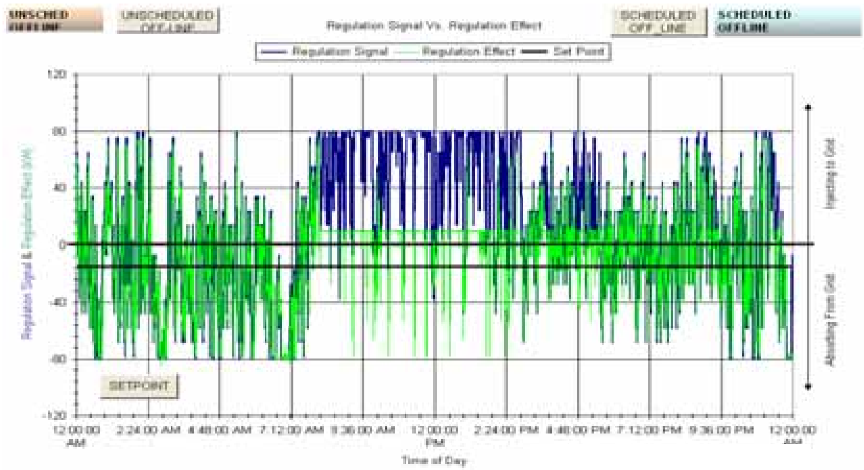

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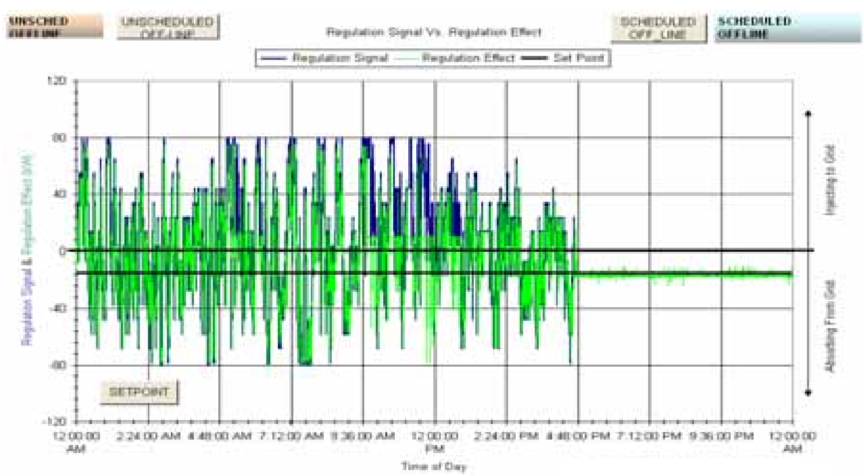

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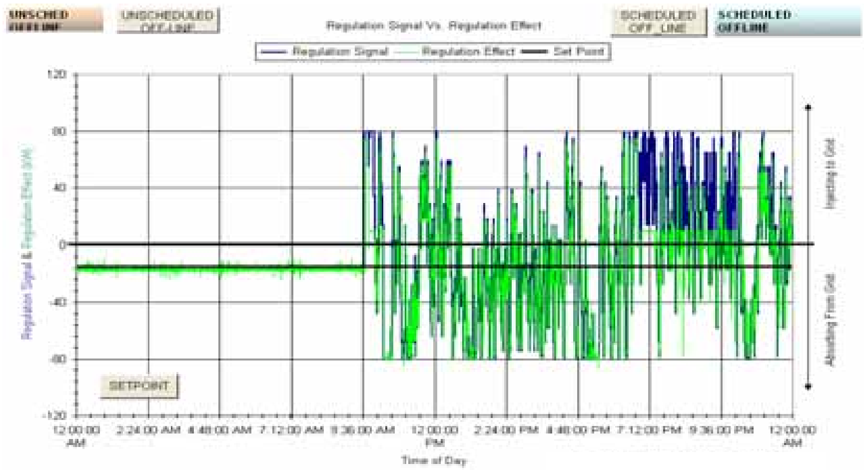

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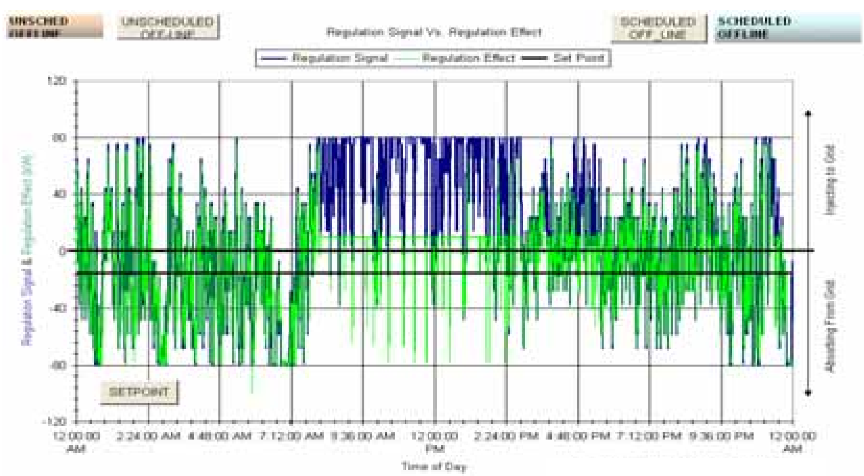

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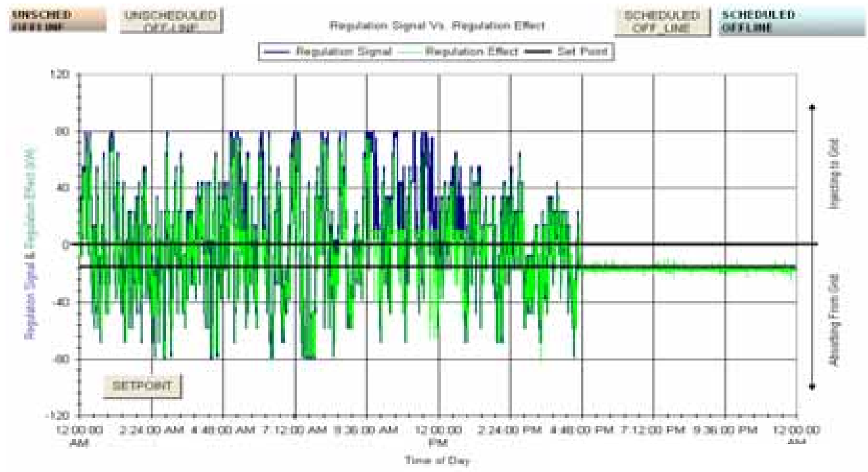

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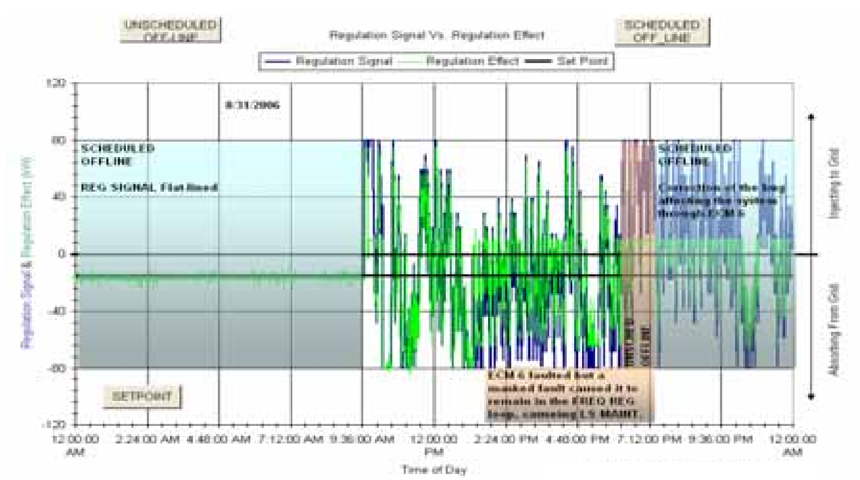
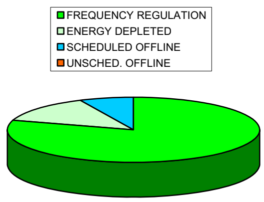


NYSERDA Run Data Monthly Summary Sheet **Date: September, 2006**

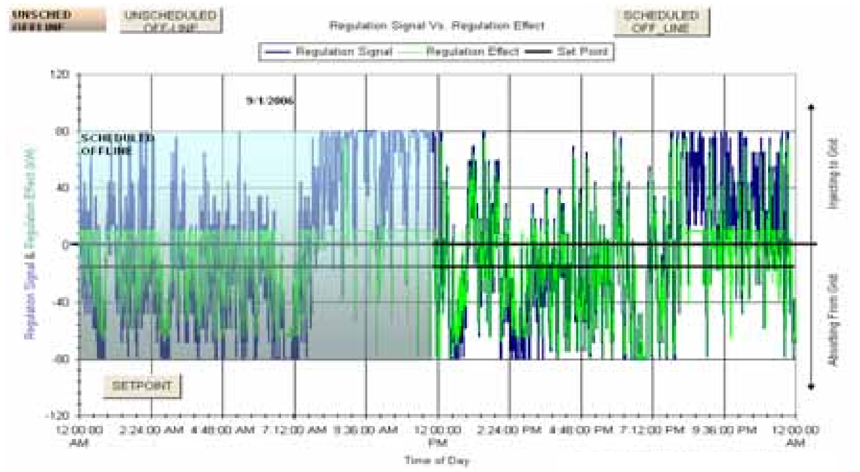
		Percent	Hours
DAILY SUMMARY	FREQUENCY REGULATION	80%	19.1
	ENERGY DEPLETED	13%	3.2
	SCHEDULED OFFLINE	7%	1.7
	UNSCHED. OFFLINE	0%	0.0
	Total	100%	24.0
	Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs	85.6%	
ON-LINE PERFORMANCE	Deviation Excluding Depleted Time	2.2%	
	Deviation Including Depleted Time	7.9%	



September, 2006 NYSERDA SEM Performance Summary

Date	Freq Reg	Energy Depleted	Total Online Hrs	Availability	Offline Unsched	Offline Sched	Deviation	Deviation w/ depletion	Max KW	Setpoint KW	Cutoff Speed RPM	Max FW's	Comment
1-Sep	10.20	1.89	12.09	84.3%	0.01	11.90	4.54%	11.04%	80	15000	17500	6	Weakness in the FR algorithm? FW 6 was allowed to spin down to 13000 RPM. Every time we absorb, its fine, but whenever we inject, we go to LOW SPEED MAINT without "needing to". Fault masked?
2-Sep	20.19	3.38	23.57	84.1%	0.43	0.00	1.90%	7.81%	80	15000	17500	6	
3-Sep	21.17	2.82	23.99	88.2%	0.01	0.00	1.94%	6.15%	80	15000	17500	6	
4-Sep	22.98	1.01	23.99	95.7%	0.01	0.00	1.98%	3.68%	80	15000	17500	6	
5-Sep	20.80	3.19	23.99	86.7%	0.01	0.00	1.97%	7.28%	80	15000	17500	6	
6-Sep	20.43	3.56	23.99	85.1%	0.01	0.00	1.90%	7.95%	80	15000	17500	6	
7-Sep	18.96	5.03	23.99	79.0%	0.01	0.00	1.99%	9.50%	80	15000	17500	6	
8-Sep	21.28	2.72	23.99	88.7%	0.01	0.00	2.07%	7.80%	80	15000	17500	6	
9-Sep	21.10	2.89	23.99	87.9%	0.01	0.00	1.86%	7.33%	80	15000	17500	6	
10-Sep	20.41	3.58	23.99	85.0%	0.01	0.00	1.94%	8.00%	80	15000	17500	6	7/25 replay
11-Sep	20.87	3.11	23.99	87.0%	0.02	0.00	2.33%	6.82%	80	15000	17500	6	7/26 replay
12-Sep	22.23	1.76	23.99	92.6%	0.02	0.00	2.56%	5.16%	80	15000	17500	6	7/27 replay
13-Sep	20.16	3.83	23.99	84.0%	0.01	0.00	2.41%	8.41%	80	15000	17500	6	7/28 replay
14-Sep	19.65	4.35	23.99	81.9%	0.01	0.00	2.42%	9.49%	80	15000	17500	6	7/29 replay
15-Sep	18.23	5.76	23.99	75.9%	0.01	0.00	2.57%	10.95%	80	15000	17500	6	7/30 replay
16-Sep	19.60	4.39	23.99	81.7%	0.01	0.00	2.31%	10.30%	80	15000	17500	6	7/31 replay
17-Sep	19.59	4.40	23.99	81.6%	0.01	0.00	2.33%	9.54%	80	15000	17500	6	
18-Sep	10.10	2.10	12.20	82.8%	0.01	11.79	2.32%	9.13%	80	15000	17500	6	FWs 1 and 2 began acting up. Vacuum loss on 1 and Desat on 2. Brought system down
19-Sep	7.32	0.95	8.28	88.4%	0.01	15.72	1.84%	6.04%	80	15000	17500	6	Changed CPLD on 1, left 1 and 2 off till vacuum pump arrives
20-Sep	20.82	3.17	23.99	86.7%	0.01	0.00	2.87%	7.59%	80	15000	17500	6	
21-Sep	20.27	3.73	23.99	84.4%	0.01	0.00	1.93%	8.40%	80	15000	17500	6	
22-Sep	19.14	4.85	23.99	79.8%	0.01	0.00	2.11%	9.41%	80	15000	17500	6	
23-Sep	20.34	3.65	23.99	84.8%	0.01	0.00	1.89%	8.92%	80	15000	17500	6	
24-Sep	20.58	3.41	23.99	85.7%	0.01	0.00	1.93%	7.81%	80	15000	17500	6	
25-Sep	11.52	2.09	13.61	84.6%	0.00	10.39	2.21%	8.33%	80	15000	17500	6	took system down to remove FW #2: Could not resume operation until MC code changed to allow a missing contactor in that location.
26-Sep	20.05	3.96	24.00	83.5%	0.00	0.00	1.87%	8.63%	80	15000	17500	6	
27-Sep	21.63	2.37	24.00	90.1%	0.00	0.00	1.79%	5.29%	80	15000	17500	6	
28-Sep	22.99	0.99	23.98	95.8%	0.03	0.00	2.11%	3.71%	80	15000	17500	6	
29-Sep	20.75	3.25	24.00	86.5%	0.00	0.00	2.18%	7.26%	80	15000	17500	6	
30-Sep	20.43	3.57	24.00	85.1%	0.00	0.00	1.90%	8.14%	80	15000	17500	6	
Avg	**19.13**	**3.19**	**22.32**	**85.6%**	**0.02**	**1.66**	**2.20%**	**7.86%**					

09-01-2006



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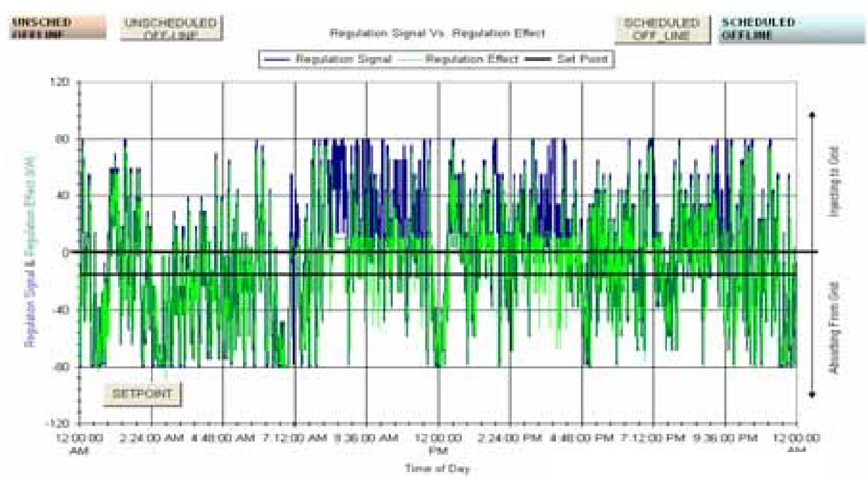

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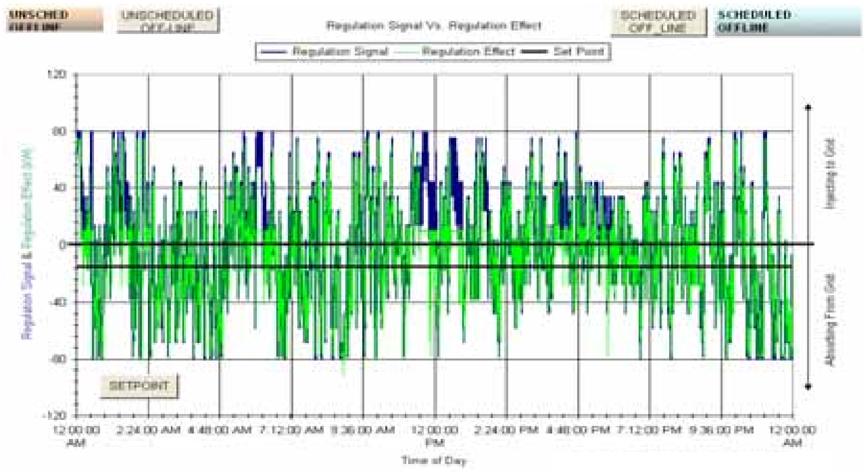

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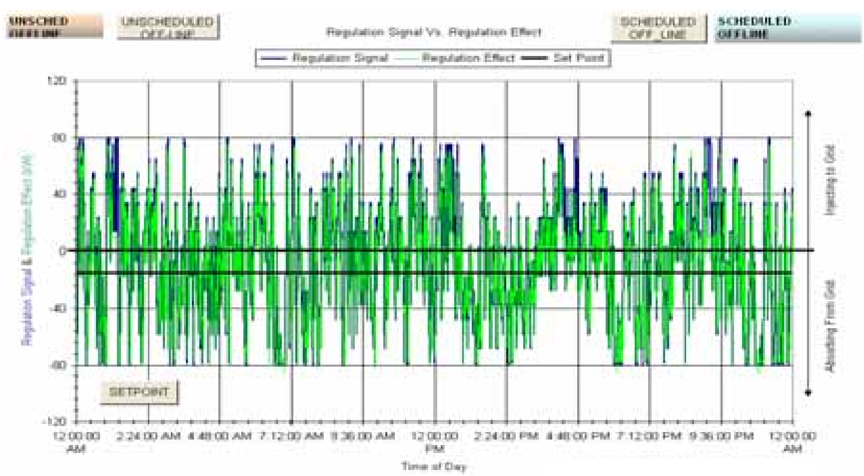

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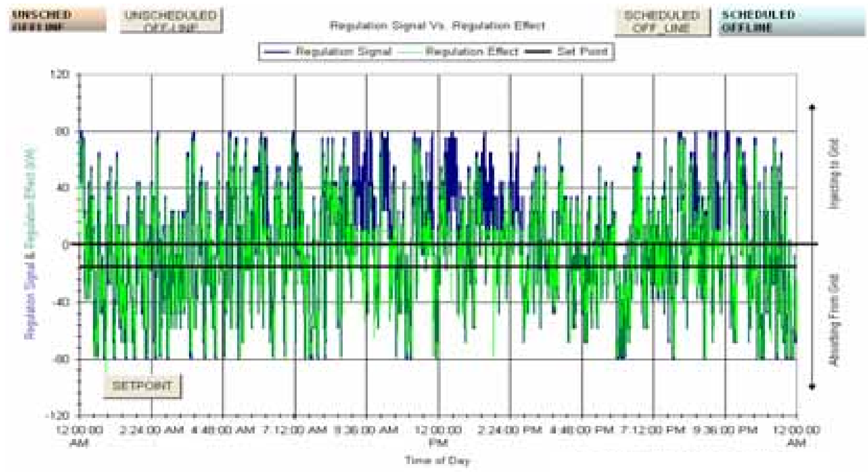

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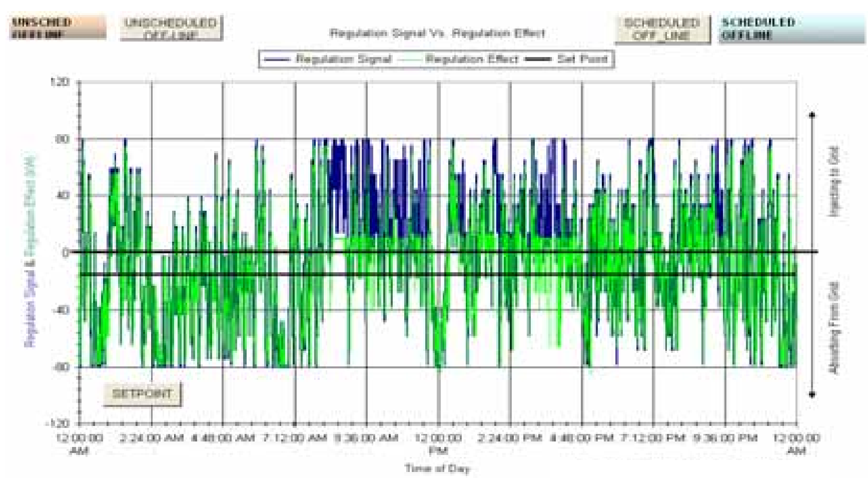

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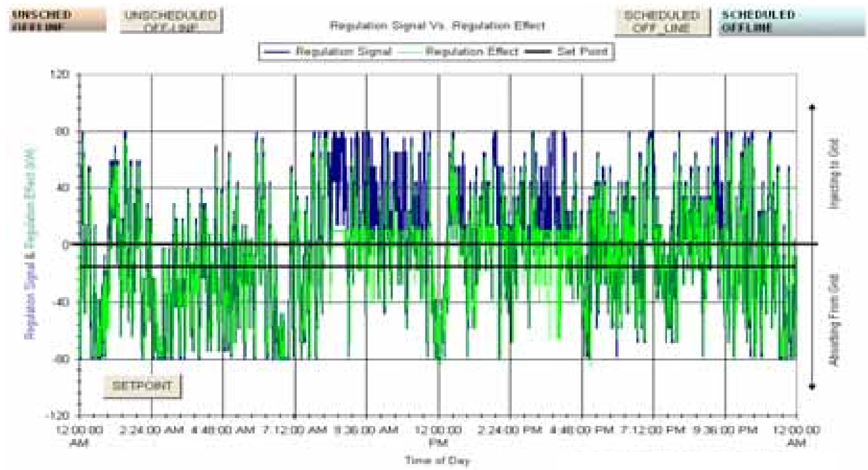

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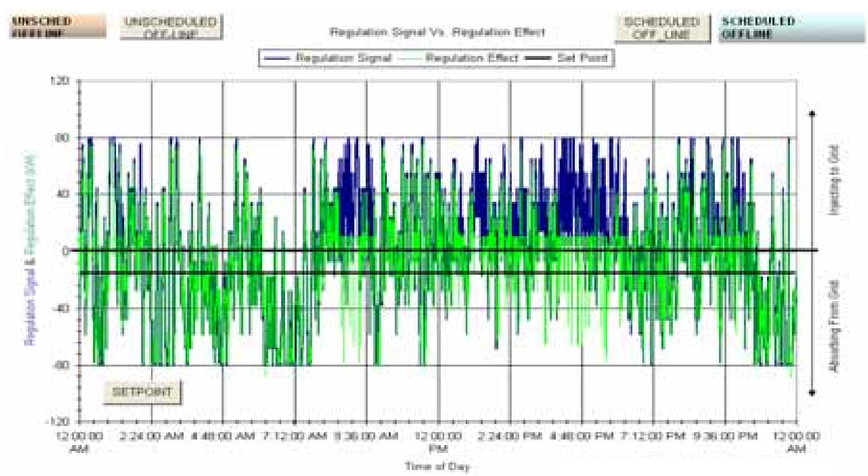

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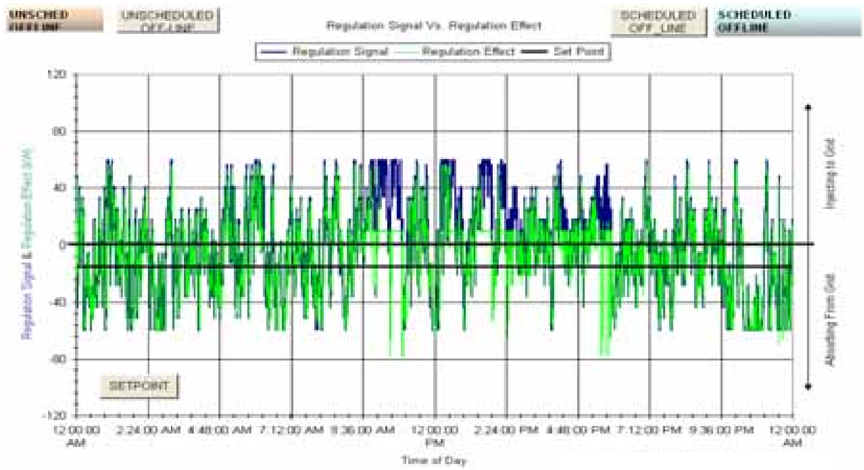

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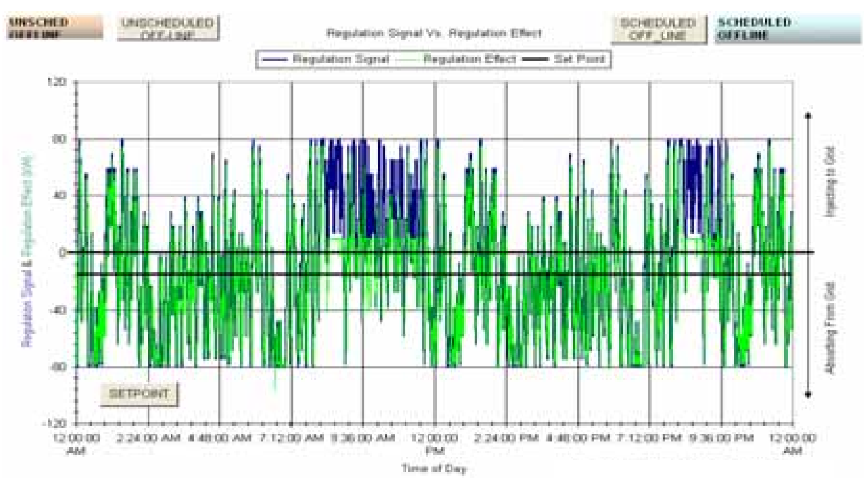

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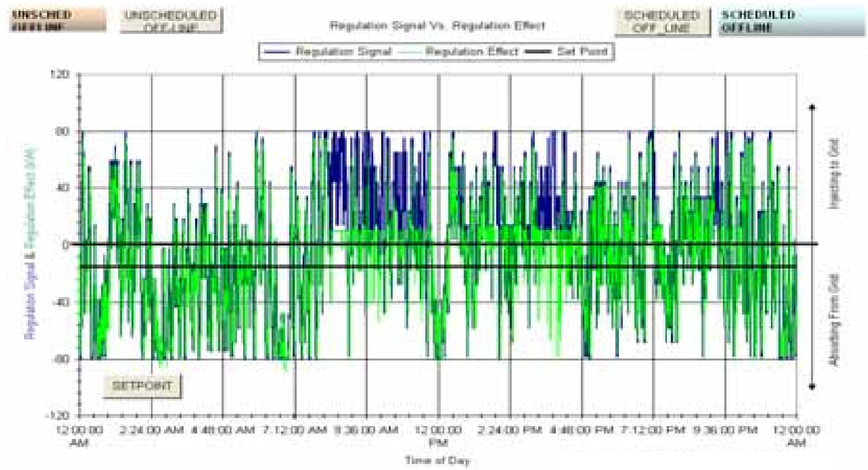

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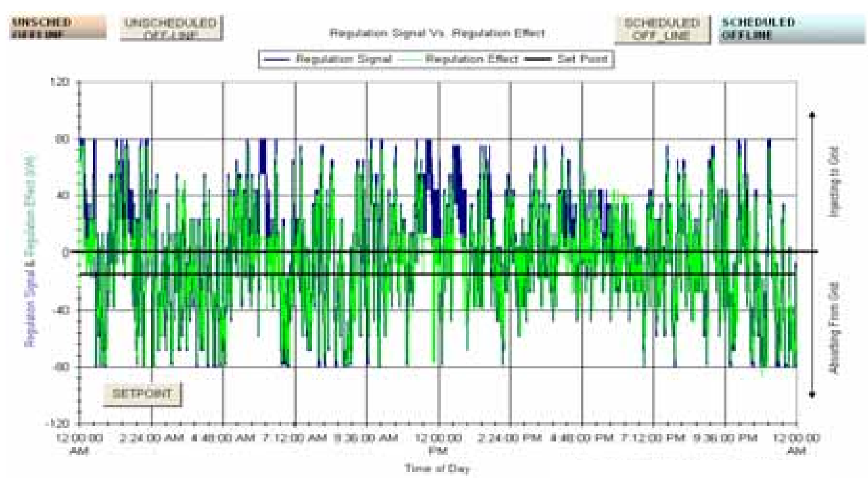

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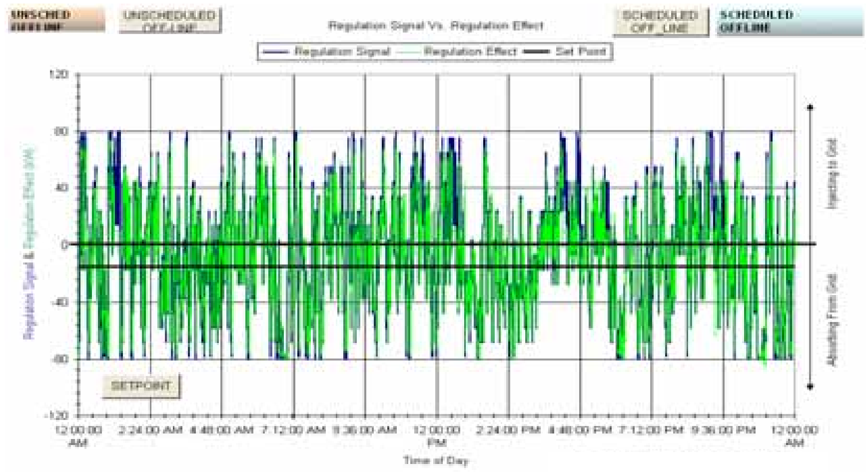

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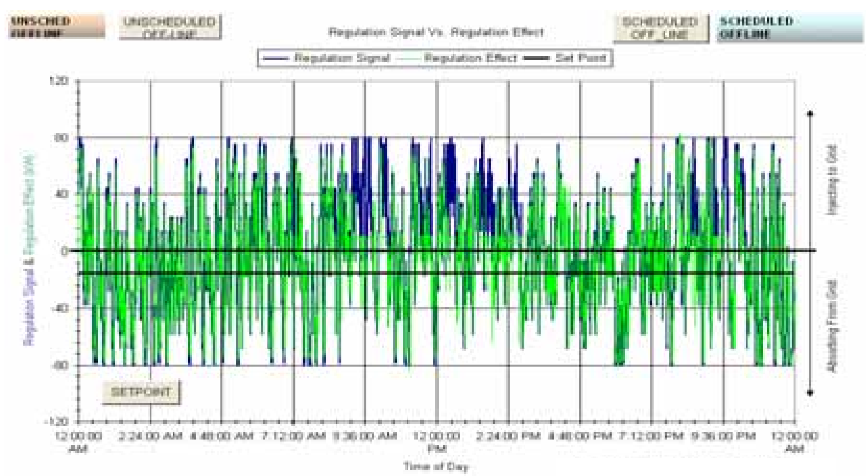

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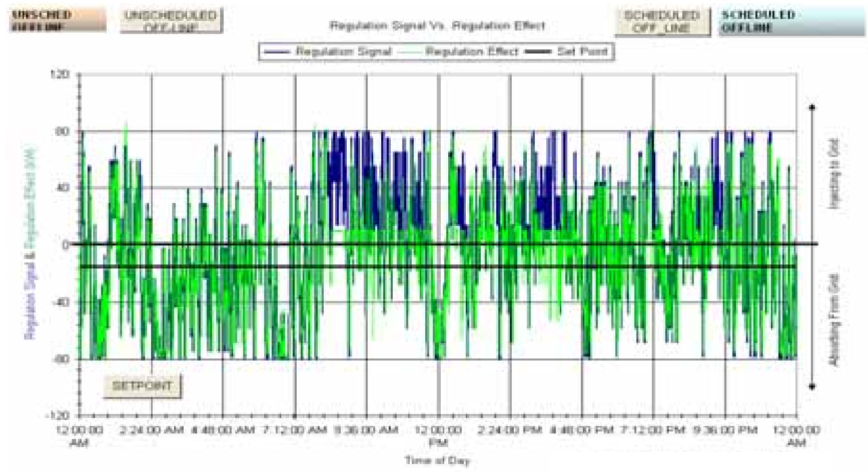

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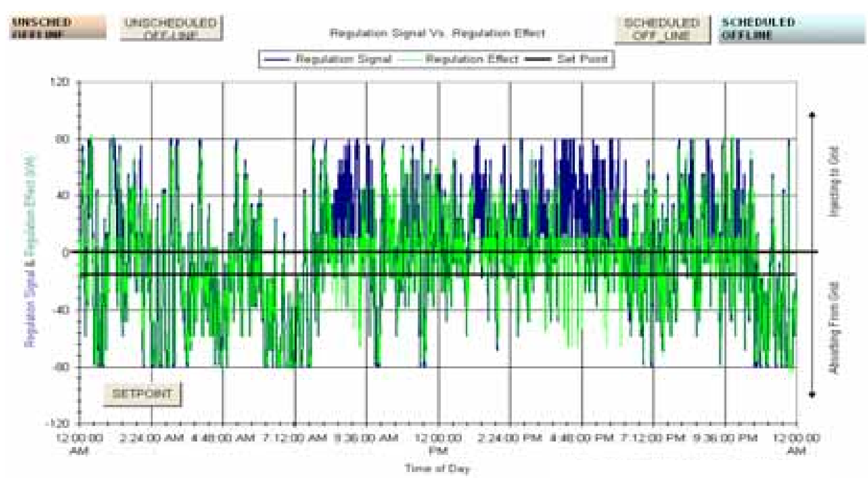

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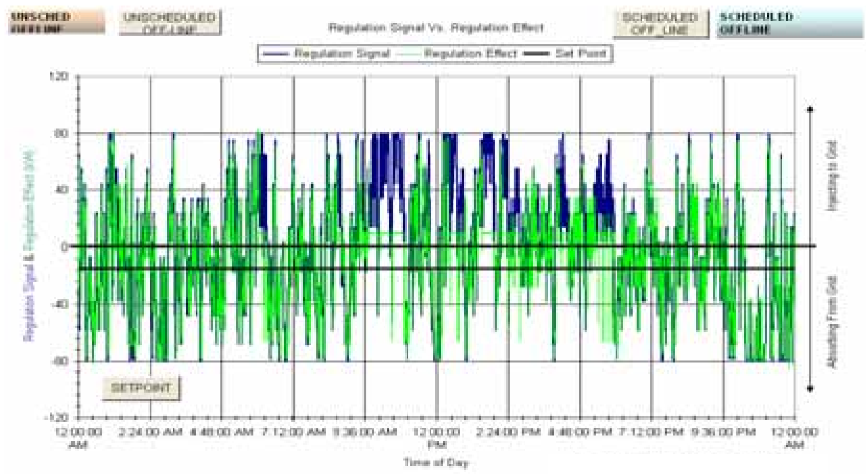

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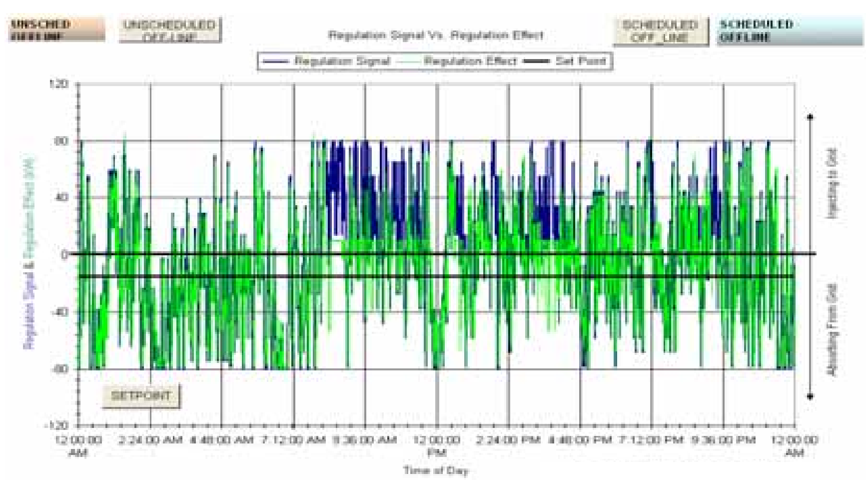

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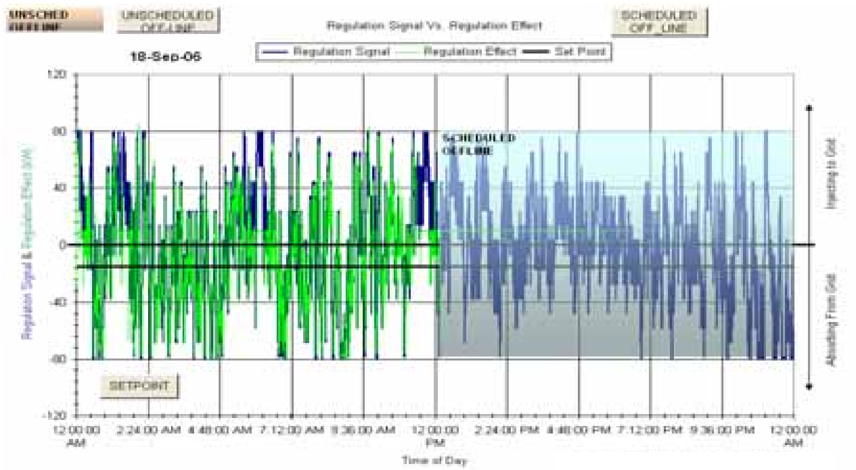

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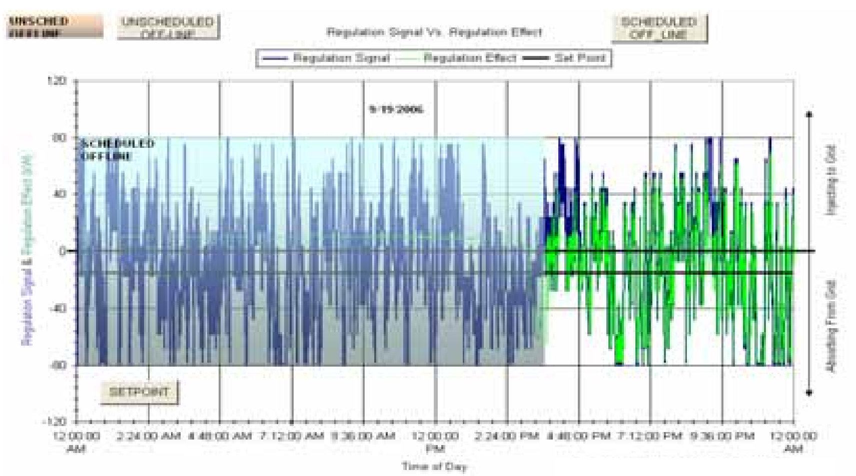

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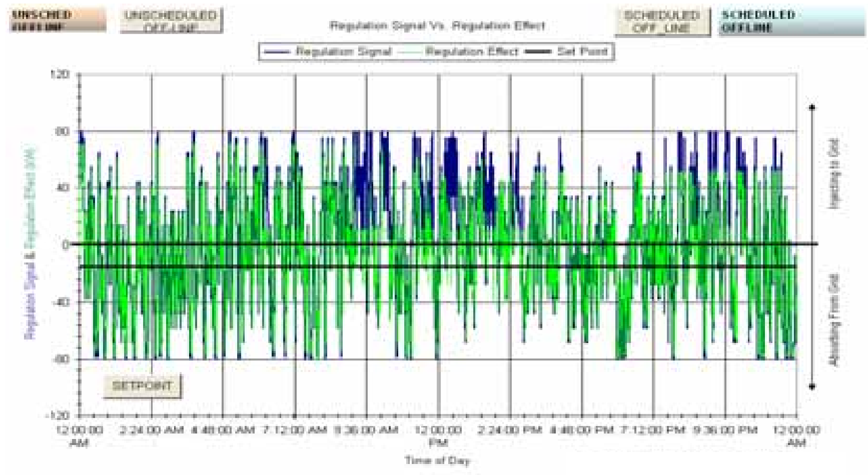

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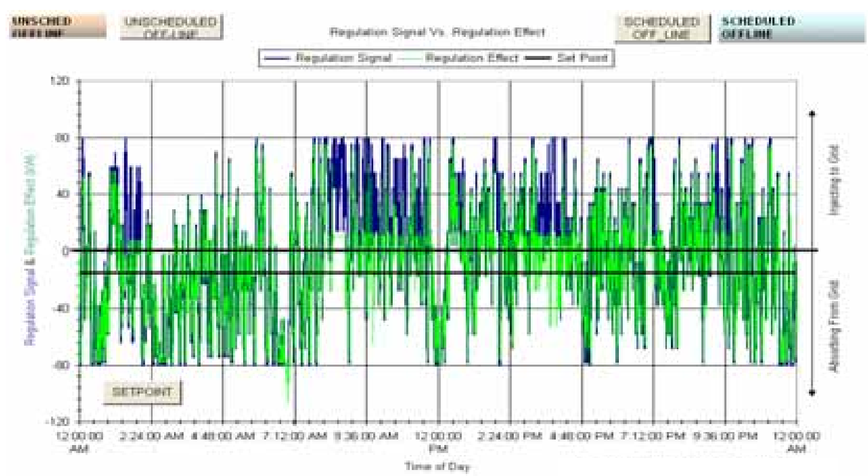

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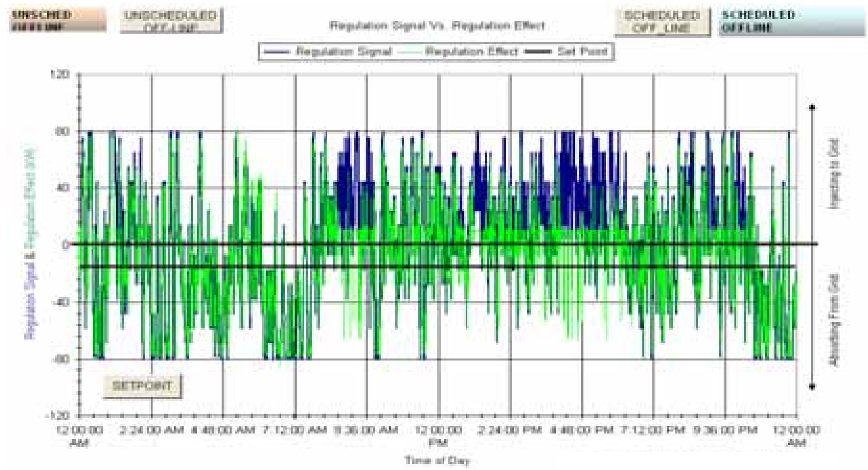

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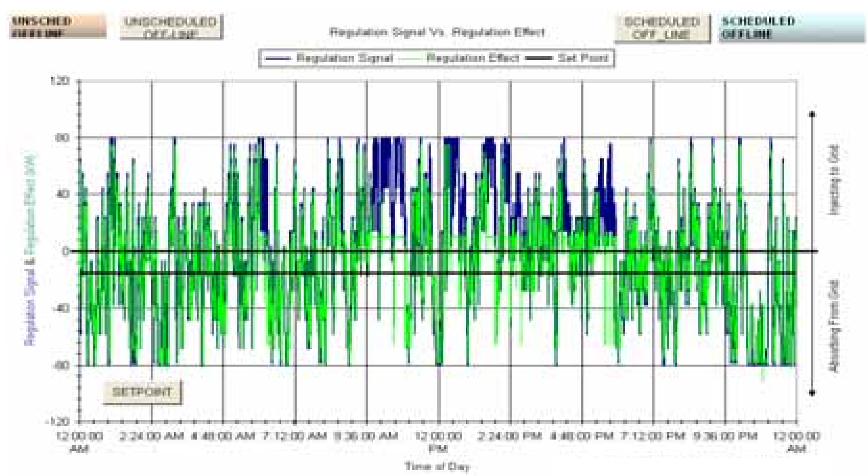

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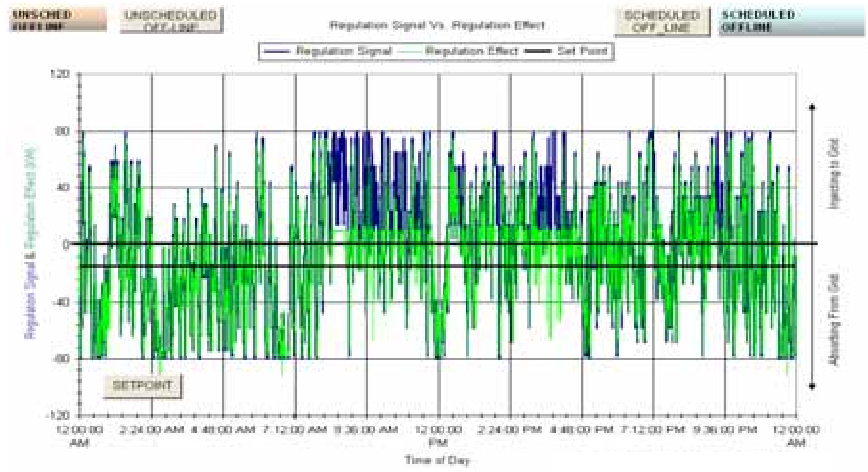

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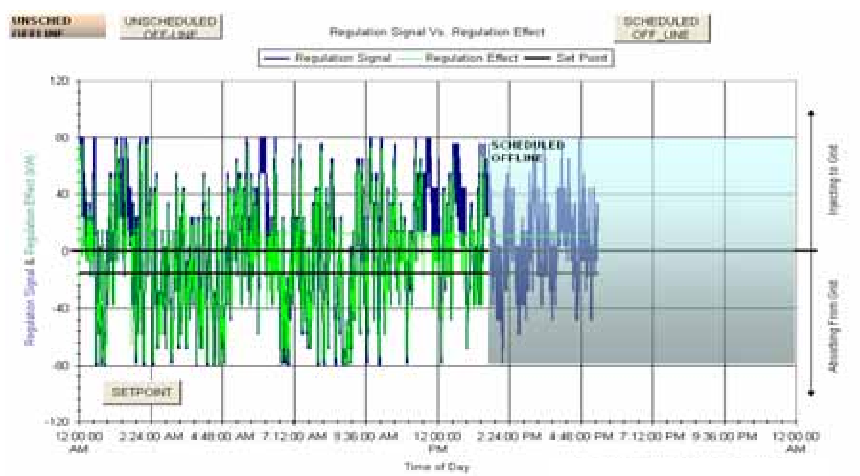

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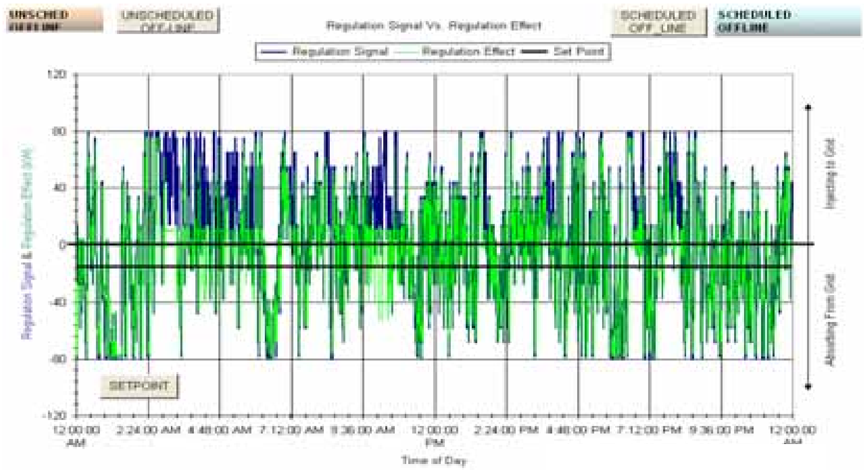

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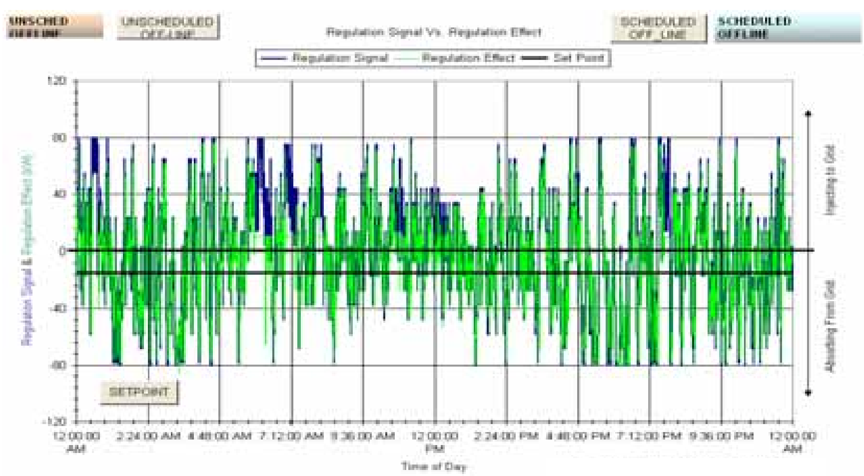

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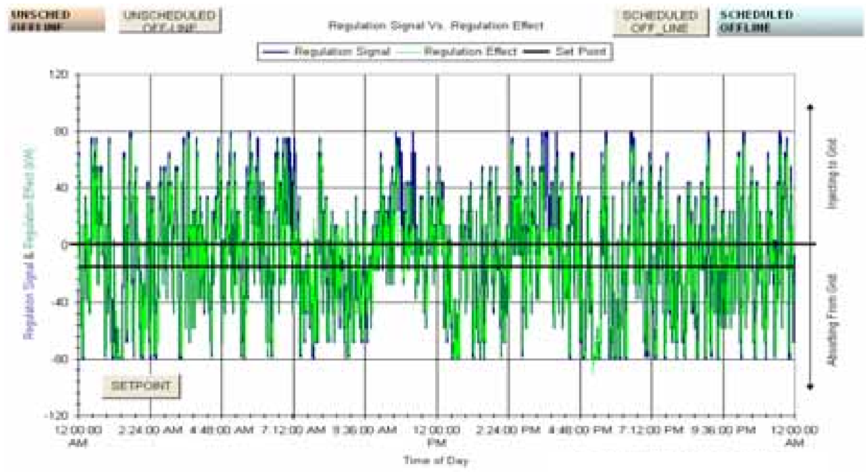

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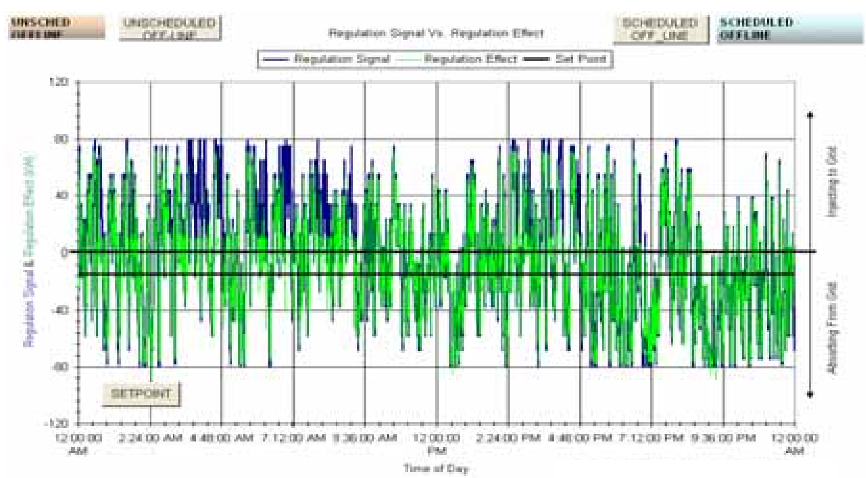

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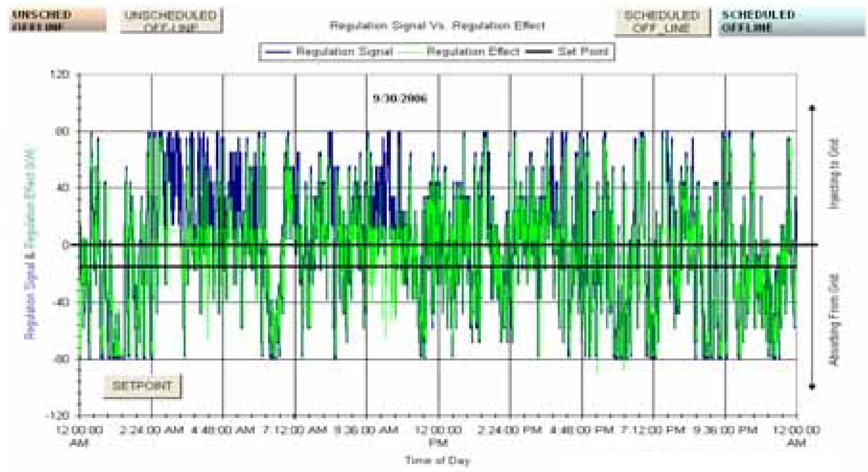
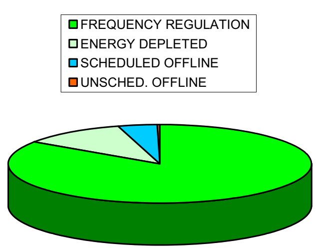


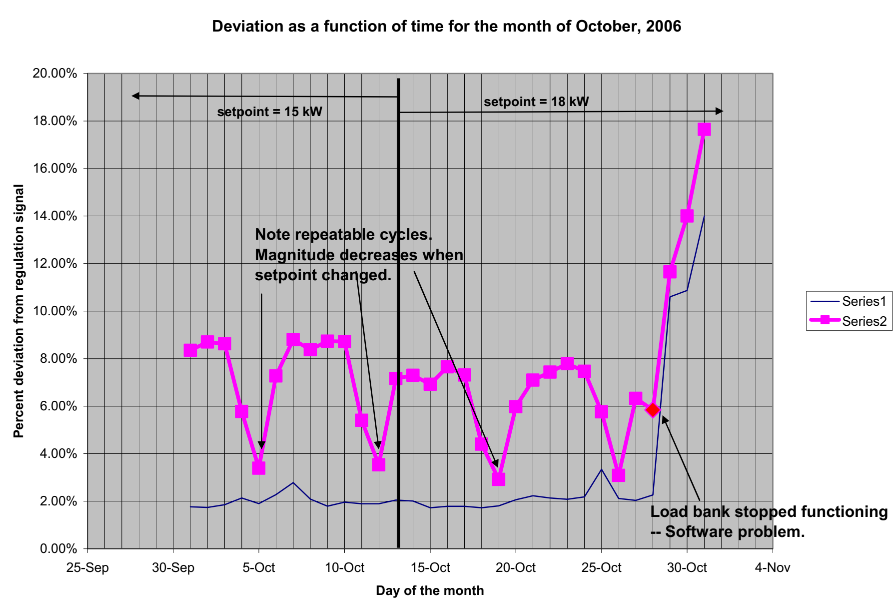
NYSERDA Run Data Monthly Summary Sheet **Date: October, 2006**

		Percent	Hours
DAILY SUMMARY	FREQUENCY REGULATION	84%	20.3
	ENERGY DEPLETED	11%	2.7
	SCHEDULED OFFLINE	4%	1.0
	UNSCHED. OFFLINE	0%	0.0
	Total	100%	24.0
ON-LINE PERFORMANCE	Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs	89.0%	
	Deviation Excluding Depleted Time	2.6%	
	Deviation Including Depleted Time	7.1%	



October, 2006 NYSERDA SEM Performance Summary

Date	Freq Reg	Energy Depleted	Total Online Hrs	Offline Unsched	Offline Sched	Avail.	Deviation	Deviation w/ depletion	Max KW	Setpoint KW	Cutoff Speed RPM	Max FW's	Comment
1-Oct	19.46	4.55	24.00	0.00	0.00	81.1%	1.76%	8.35%	80	15	17500	6	
2-Oct	20.39	3.61	24.00	0.00	0.00	85.0%	1.74%	8.70%	80	15	17500	6	
3-Oct	20.02	3.98	24.00	0.00	0.00	83.4%	1.86%	8.63%	80	15	17500	6	
4-Oct	21.54	2.41	23.95	0.05	0.00	89.7%	2.14%	5.77%	80	15	17500	6	
5-Oct	23.10	0.90	24.00	0.00	0.00	96.3%	1.90%	3.39%	80	15	17500	6	
6-Oct	20.70	3.23	23.93	0.08	0.00	86.2%	2.28%	7.27%	80	15	17500	6	
7-Oct	20.33	3.64	23.97	0.03	0.00	84.7%	2.79%	8.80%	80	15	17500	6	
8-Oct	19.62	4.23	23.85	0.15	0.00	81.7%	2.09%	8.38%	80	15	17500	6	
9-Oct	20.36	3.64	24.00	0.00	0.00	84.8%	1.80%	8.73%	80	15	17500	6	
10-Oct	20.02	3.92	23.94	0.06	0.00	83.4%	1.96%	8.72%	80	15	17500	6	ECM 3 faulted on vibes for 3 hrs
11-Oct	21.58	2.41	23.99	0.01	0.00	89.9%	1.89%	5.41%	80	15	17500	6	ECM 3 faulted on vibes twice
12-Oct	22.95	1.03	23.98	0.02	0.00	95.6%	1.89%	3.53%	80	15	17500	6	
13-Oct	20.76	3.24	24.00	0.00	0.00	86.5%	2.05%	7.16%	80	18	17500	6	
14-Oct	20.71	3.17	23.88	0.13	0.00	86.3%	2.01%	7.30%	80	18	17500	6	
15-Oct	20.15	3.85	24.00	0.00	0.00	84.0%	1.73%	6.92%	80	18	17500	6	
16-Oct	20.84	3.16	24.00	0.00	0.00	86.8%	1.78%	7.65%	80	18	17500	6	
17-Oct	20.59	3.42	24.00	0.00	0.00	85.8%	1.79%	7.31%	80	18	17500	6	
18-Oct	22.13	1.87	24.00	0.00	0.00	92.2%	1.72%	4.40%	80	18	17500	6	
19-Oct	23.33	0.67	24.00	0.00	0.00	97.2%	1.81%	2.92%	80	18	17500	6	
20-Oct	21.40	2.60	24.00	0.00	0.00	89.2%	2.07%	5.98%	80	18	17500	6	
21-Oct	21.06	2.94	24.00	0.00	0.00	87.7%	2.23%	7.09%	80	18	17500	6	
22-Oct	19.83	3.88	23.70	0.30	0.00	82.6%	2.14%	7.43%	80	18	17500	6	
23-Oct	20.84	3.16	24.00	0.00	0.00	86.8%	2.08%	7.79%	80	18	17500	6	
24-Oct	20.69	3.32	24.00	0.00	0.00	86.2%	2.18%	7.47%	80	18	17500	6	
25-Oct	22.13	1.71	23.83	0.17	0.00	92.2%	3.34%	5.76%	80	18	17500	6	
26-Oct	23.38	0.62	24.00	0.00	0.00	97.4%	2.11%	3.09%	80	18	17500	6	
27-Oct	21.28	2.72	24.00	0.00	0.00	88.7%	2.03%	6.33%	80	18	17500	6	
28-Oct	22.05	1.96	24.00	0.00	0.00	91.9%	2.26%	5.84%	60	15	17500	7	Unscheduled downtime due to faults = 1 hr. Scheduled downtime: Lost regulation Signal Hypothesis: Perhaps the load bank stopped functioning at this point.
29-Oct	7.86	0.14	8.00	0.00	17.05	113.1%	10.60%	11.65%	80	18	17500	6	Switch to daylight savings. 25 hour day. System was brought back online at 16:00 with 6 FWs
30-Oct	9.68	0.65	10.33	0.00	13.66	93.7%	10.87%	14.00%	80	18	17500	5	During early AM we were running with too few FWs due to ECM faults. During most of the rest of the day. The regulation signal was bad.
31-Oct	16.32	3.04	19.35	0.15	4.50	83.7%	14.00%	17.65%	80	18	17500	5	FW #1 faulted fo 8 hours. Others were faulted at various times. Notably #7.
AVG	**20.29**	**2.69**	**22.98**	**0.03**	**1.02**	**89.0%**	**2.63%**	**7.06%**					



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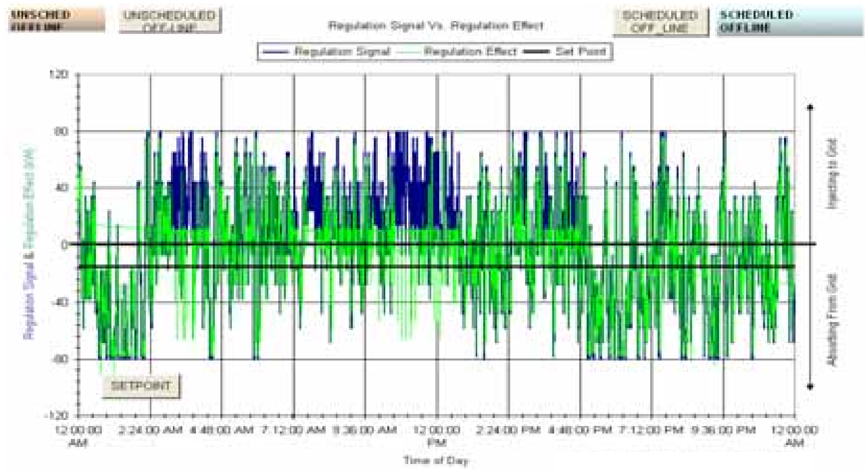

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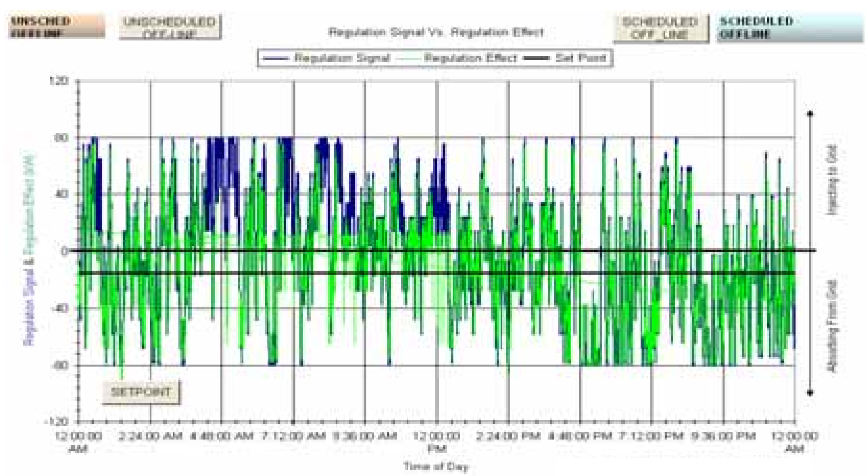

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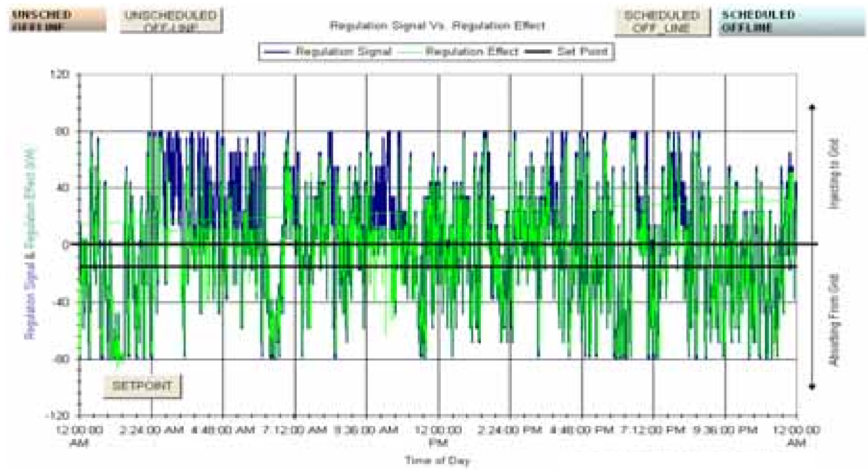

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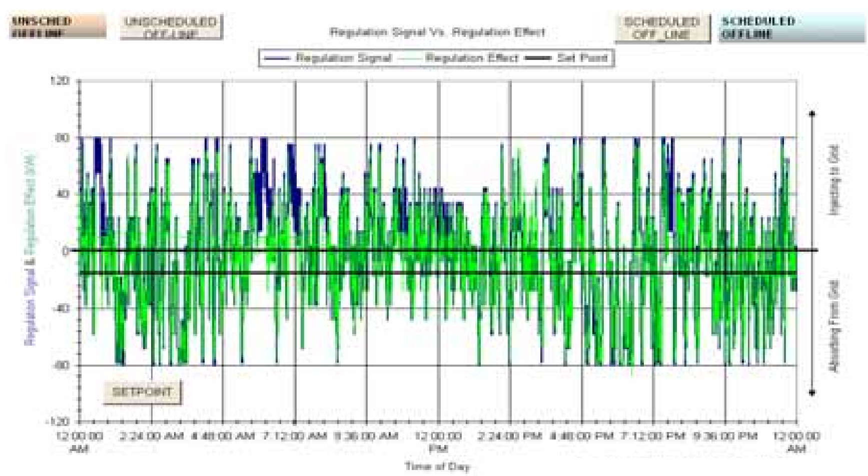

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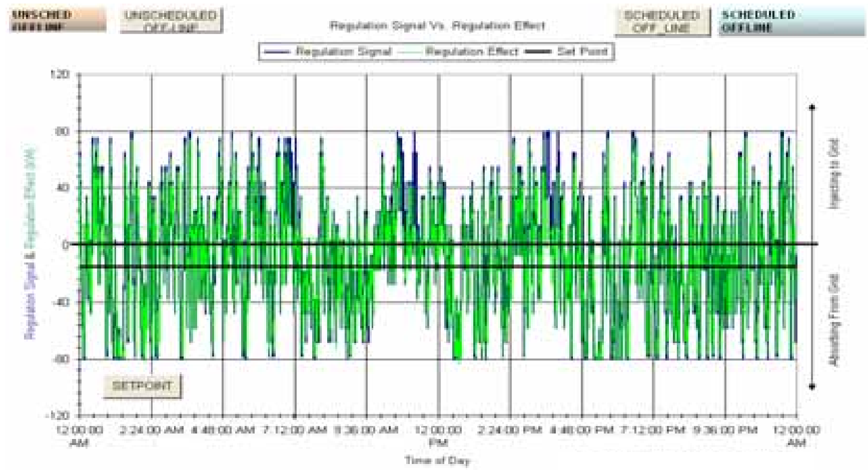

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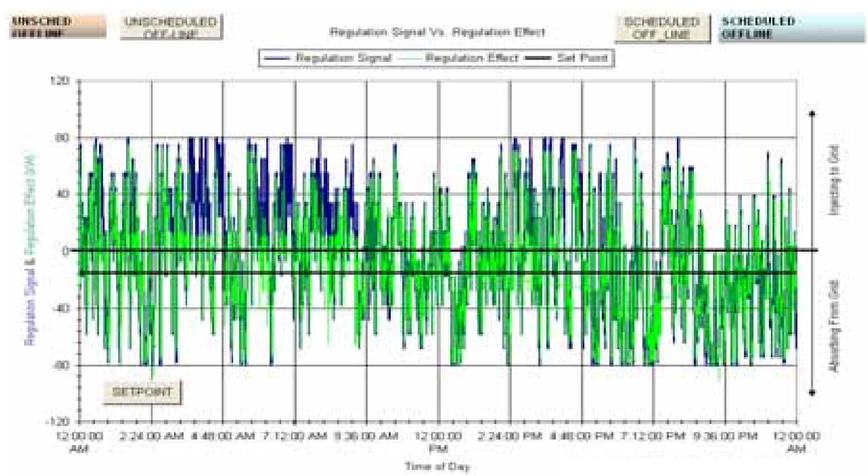

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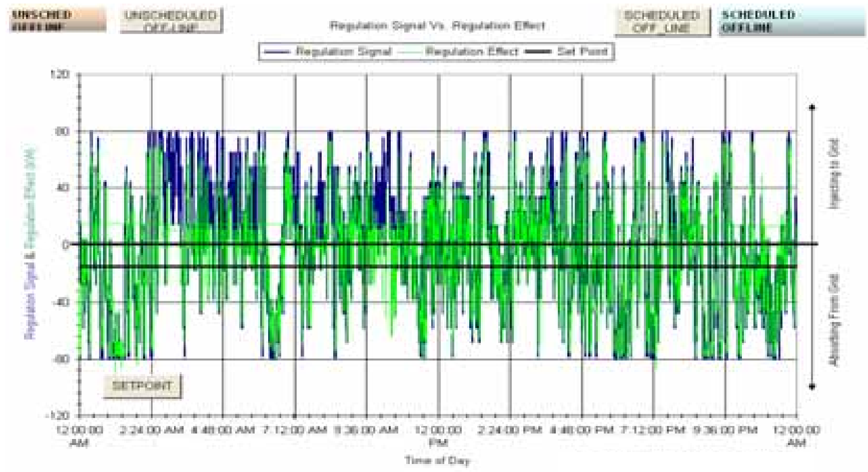

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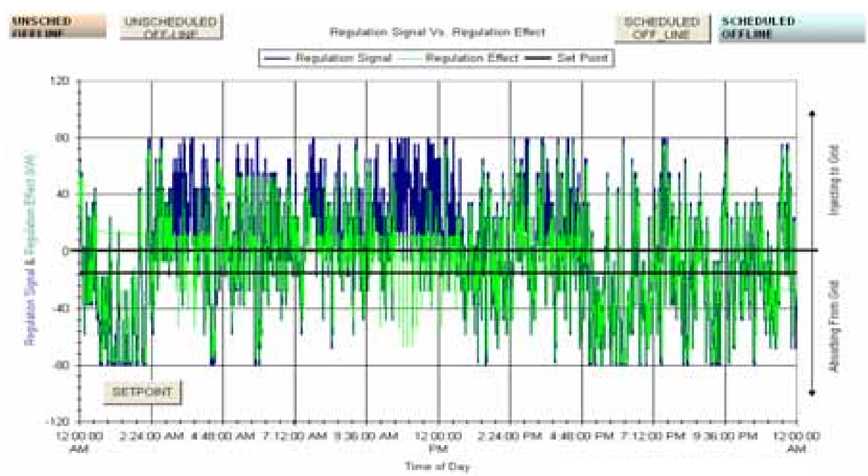

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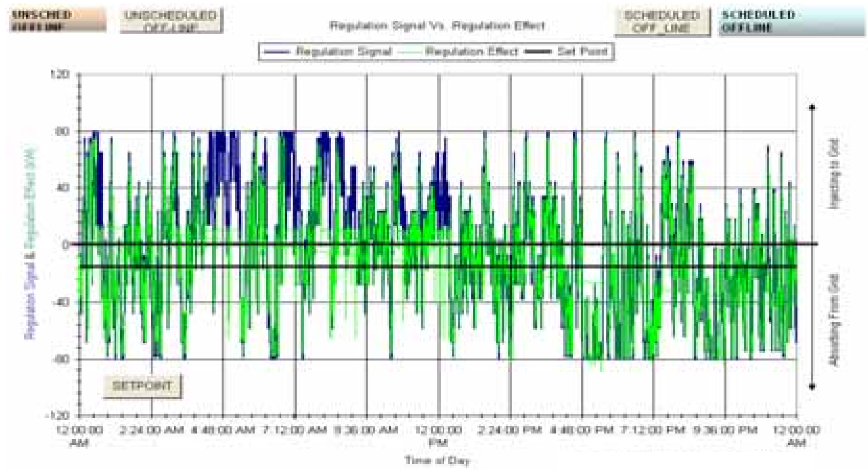

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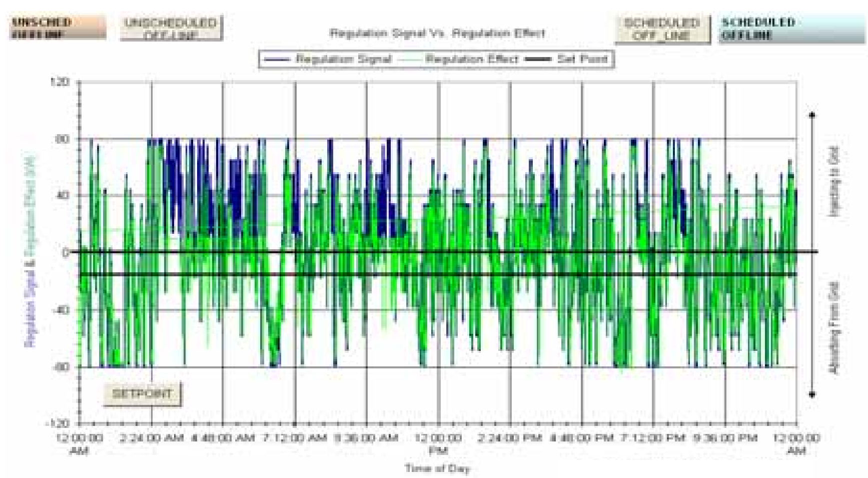

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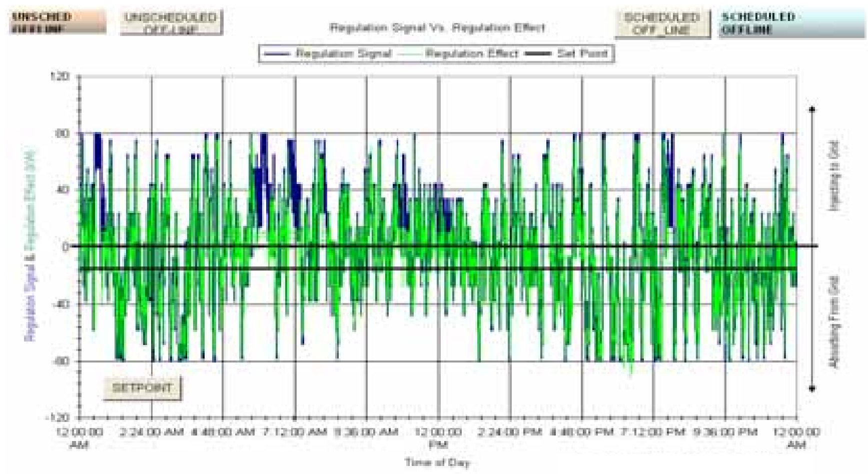

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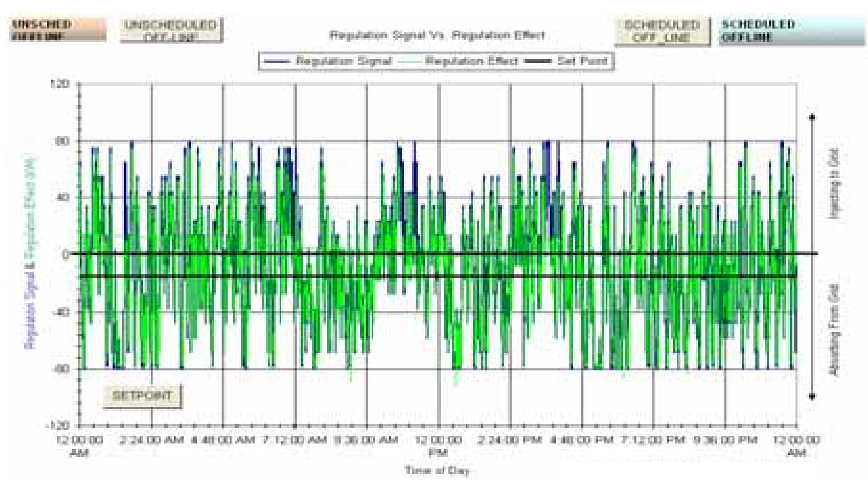

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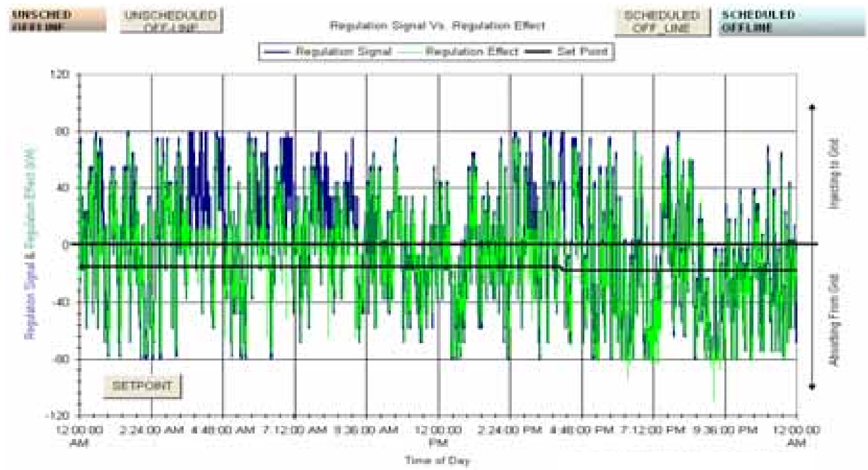

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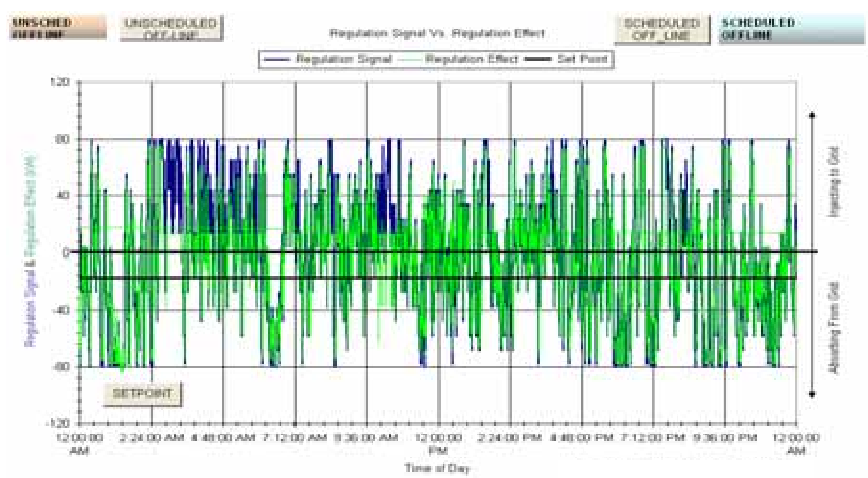

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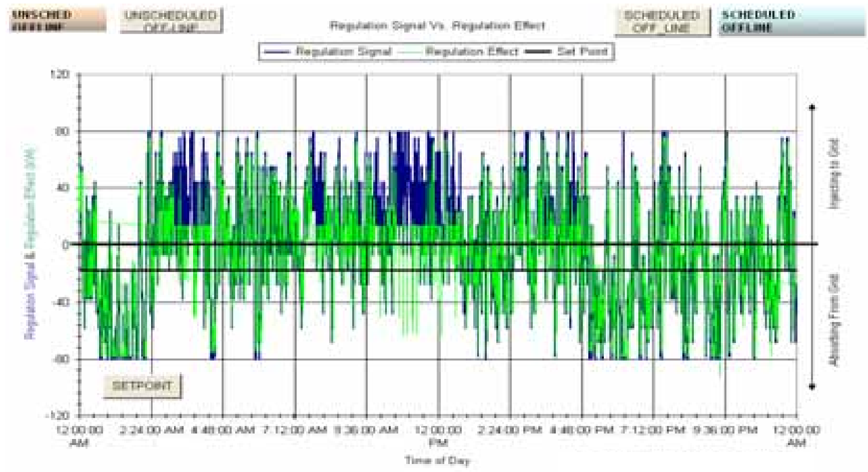

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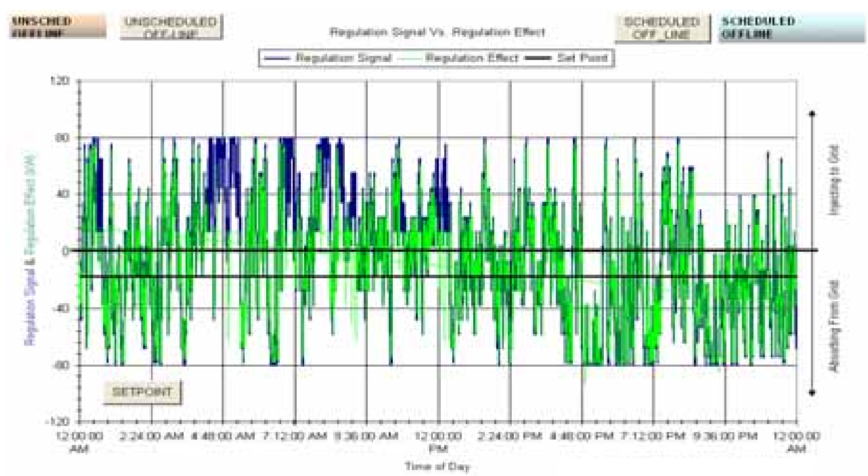

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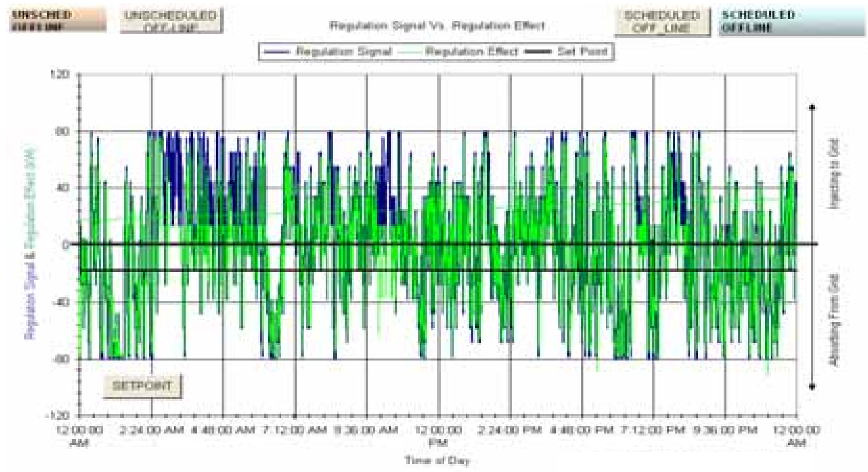

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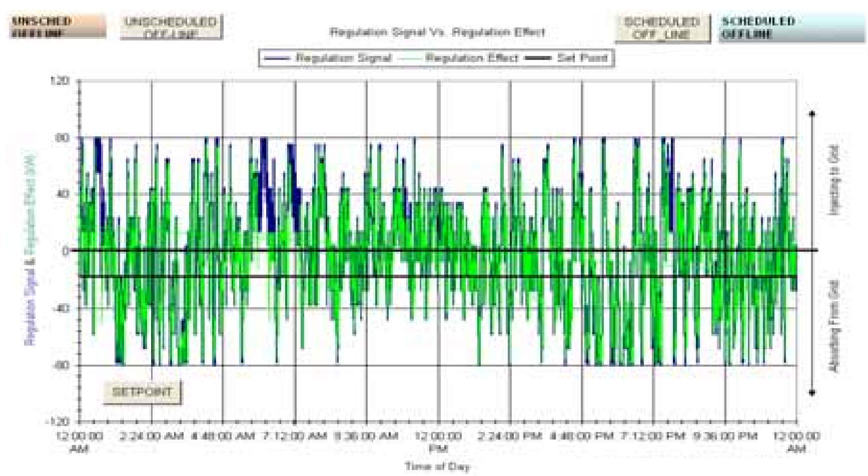

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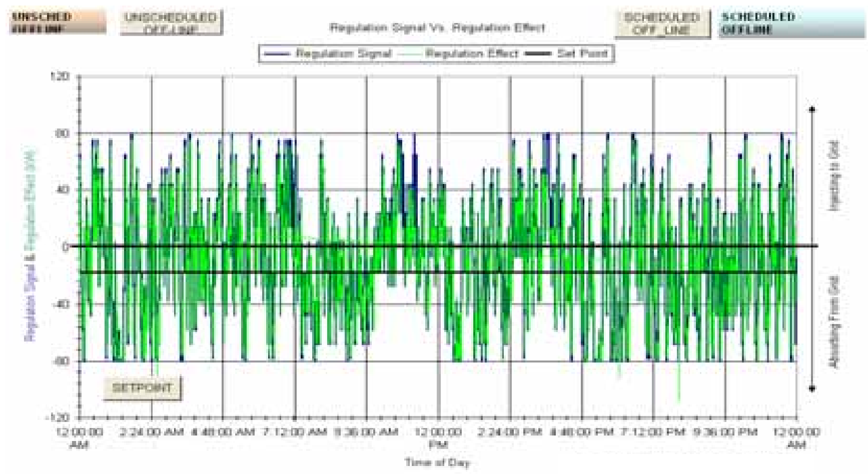

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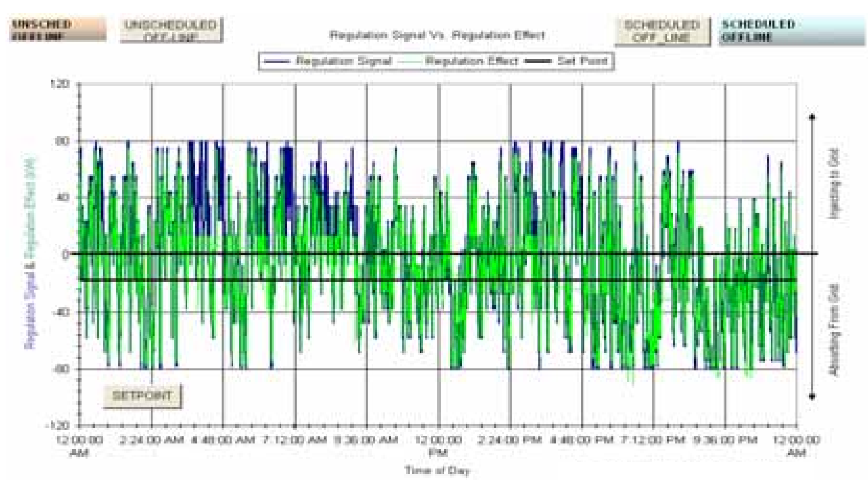

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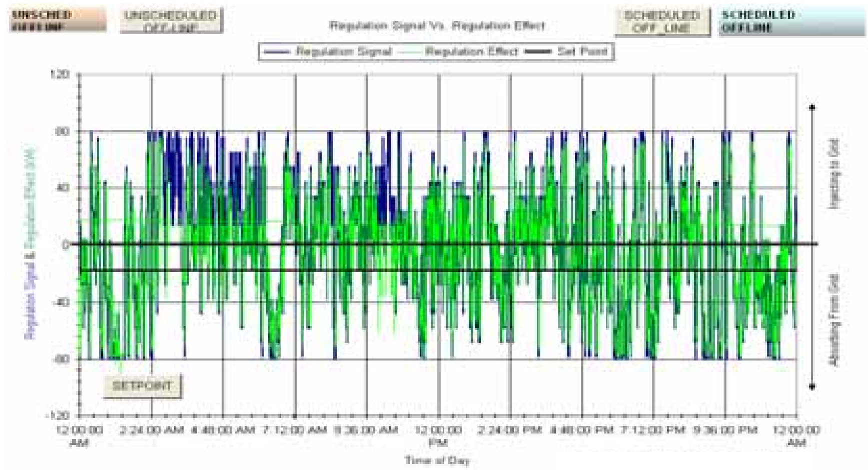

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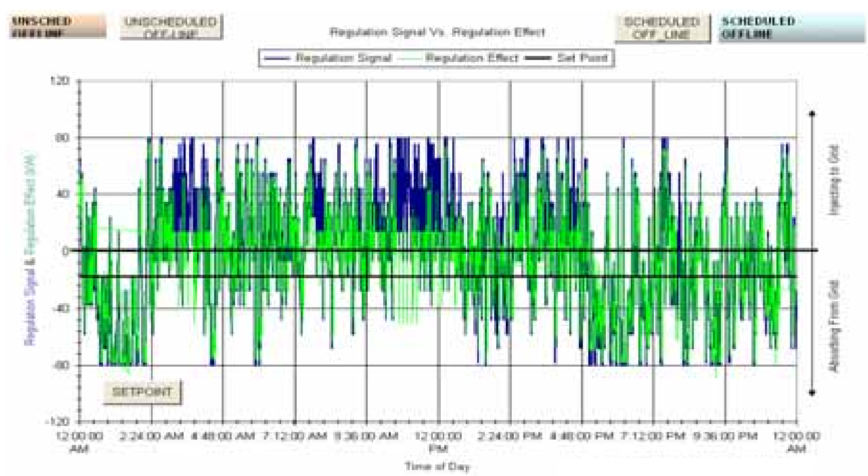

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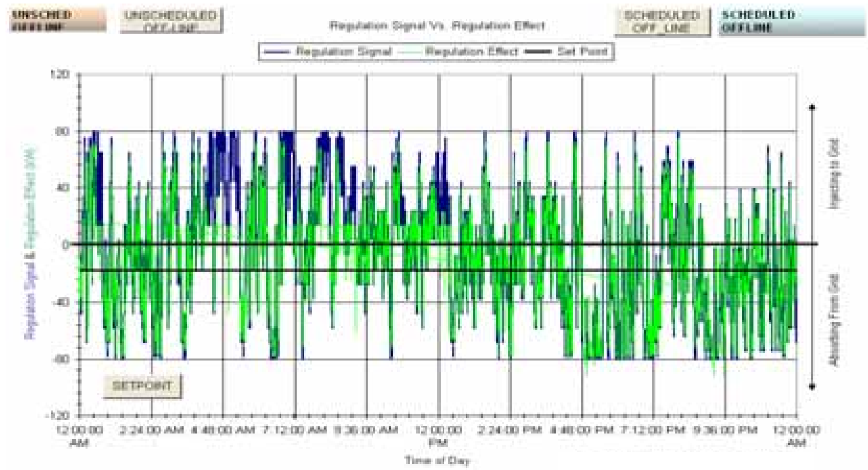

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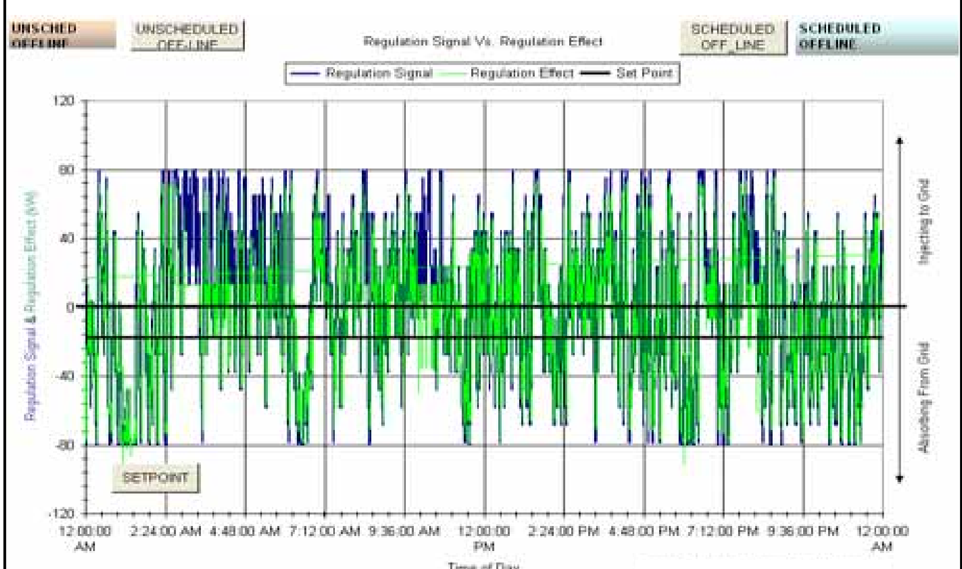

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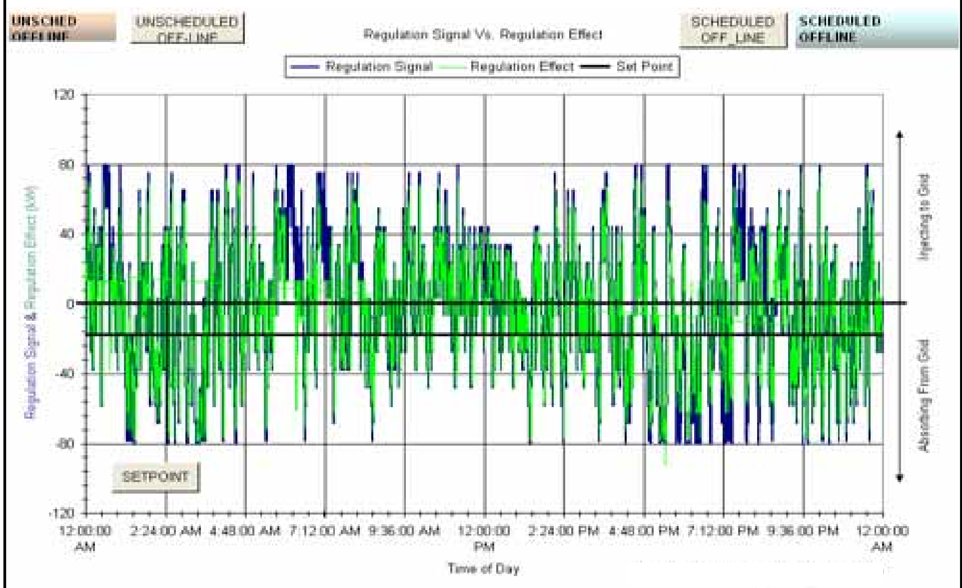

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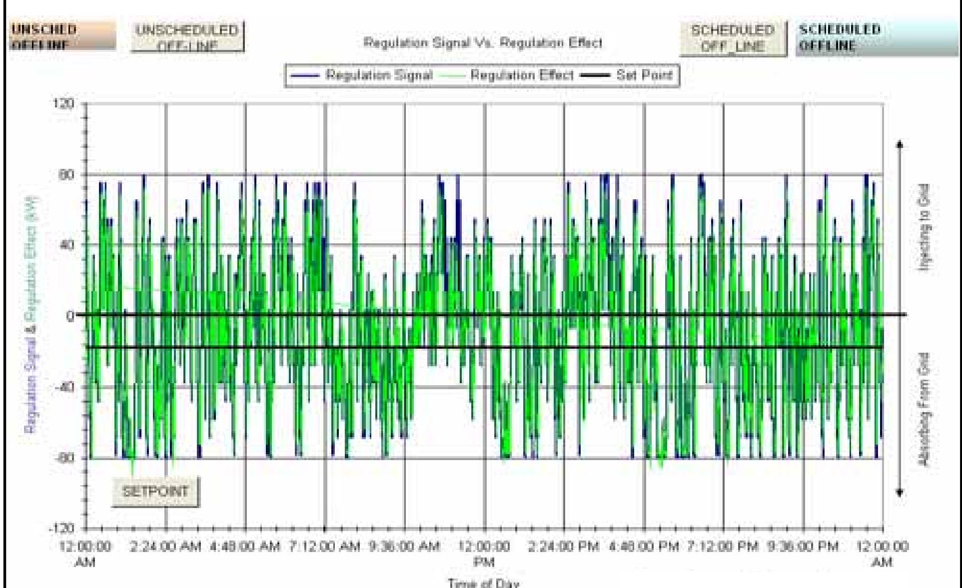
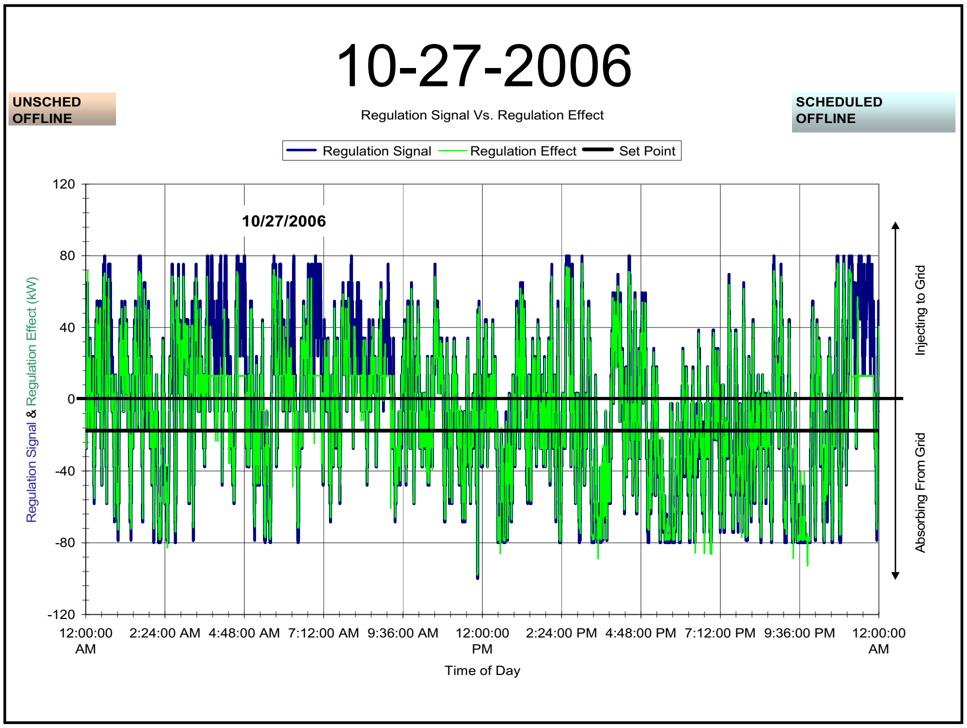
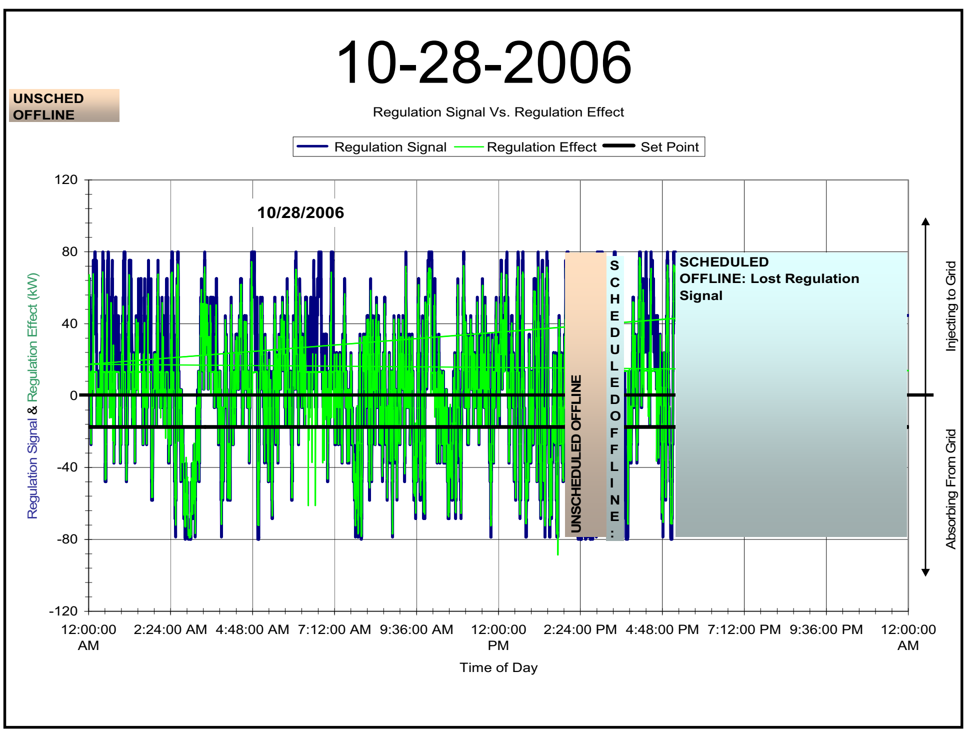



10-27-2006
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
10/27/2006
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day


10-28-2006
UNSCHED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
10/28/2006
UNSCHEDULED OFFLINE
SCHEDULED OFFLINE
SCHEDULED OFFLINE: Lost Regulation Signal
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
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2:24:00 PM
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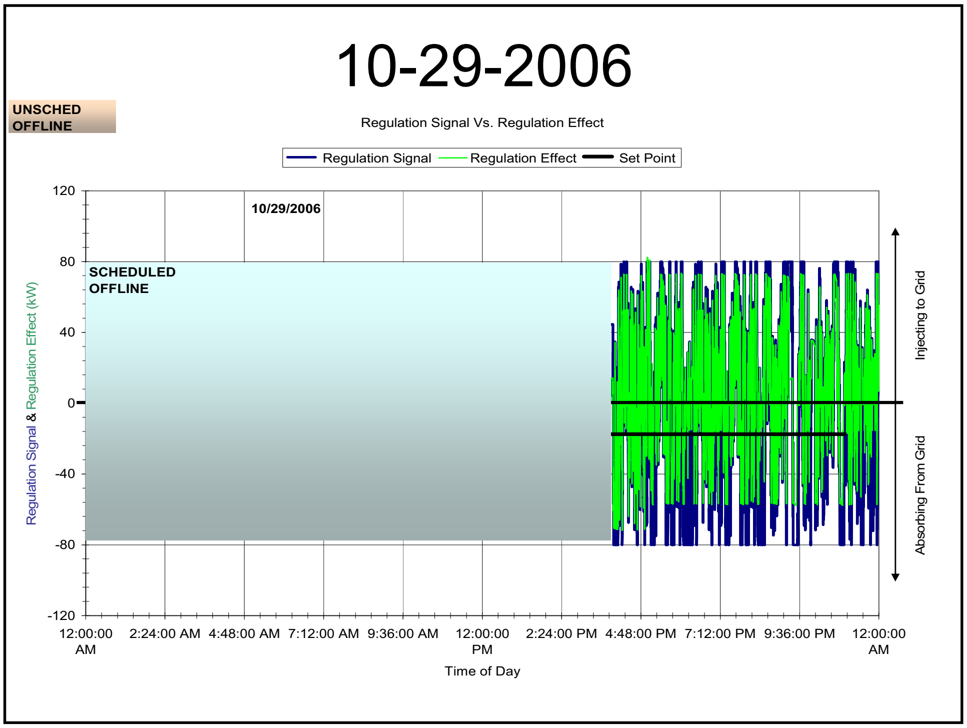
12:00:00 AM
Time of Day



10-29-2006
UNSCHED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
10/29/2006
SCHEDULED OFFLINE
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
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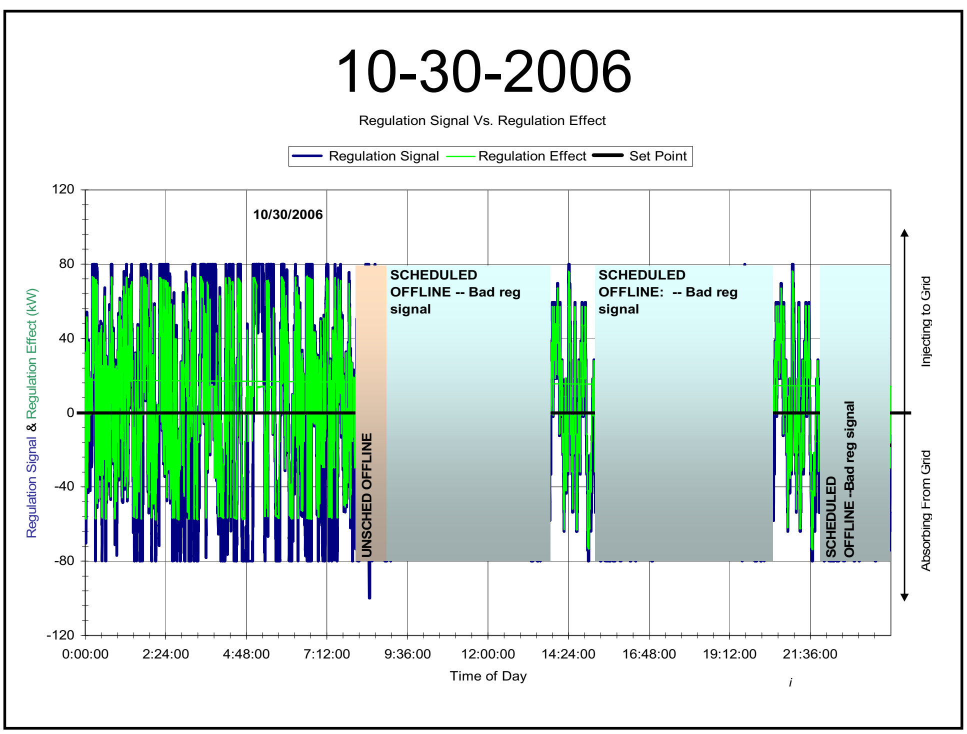
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day



10-30-2006
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
10/30/2006
UNSCHED OFFLINE
SCHEDULED OFFLINE -- Bad reg signal
SCHEDULED OFFLINE: -- Bad reg signal
SCHEDULED OFFLINE -Bad reg signal
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
120
80
40
0
-40
-80
-120
0:00:00
2:24:00
4:48:00
7:12:00
9:36:00
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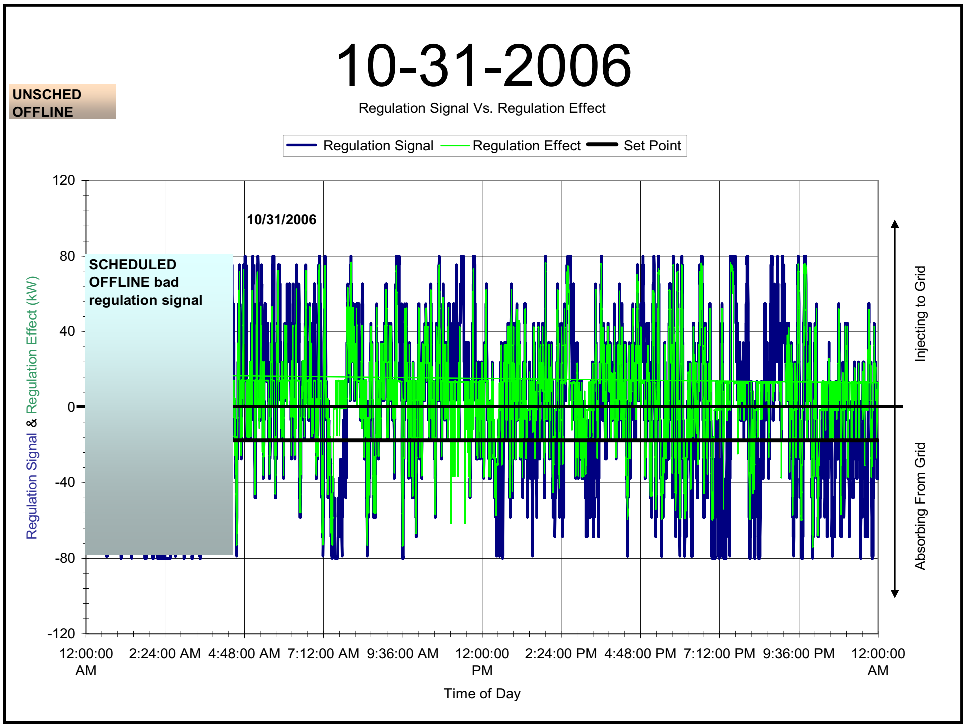
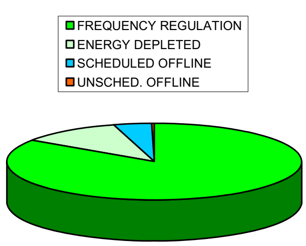
14:24:00
16:48:00
19:12:00
21:36:00
Time of Day



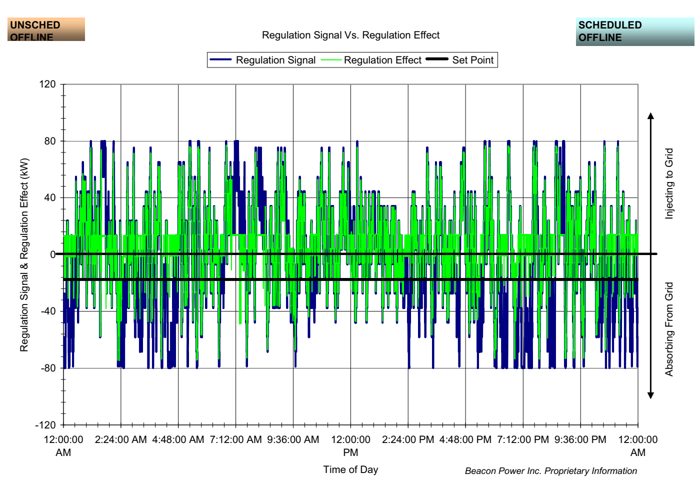
NYSERDA Run Data Monthly Summary Sheet **Date: Nov**

		Percent	Hours
DAILY SUMMARY	**FREQUENCY REGULATION**	**84%**	**18.2**
	ENERGY DEPLETED	**11%**	**2.3**
	SCHEDULED OFFLINE	**4%**	**3.3**
	UNSCHED. OFFLINE	**0%**	**0.2**
	Total	**100%**	**24.0**
ON-LINE PERFORMANCE	**Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs**	**87.7%**	
	Deviation Excluding Depleted Time	**6.9%**	
	Deviation Including Depleted Time	**10.5%**	



October, 2006 NYSERDA SEM Performance Summary													
Date	**Freq Reg**	**Energy Depleted**	**Total Online Hrs**	**Offline Unsched**	**Offline Sched**	**Avail.**	**Deviation**	**Deviation w/ depletion**	**Max KW**	**Setpoint KW**	**Cutoff Speed RPM**	**Max FW's**
1-Nov	22.03	1.98	24.00	0.00	0.00	91.8%	15.14%	16.70%	80	18	17500	6
2-Nov	23.30	0.70	24.00	0.00	0.00	97.1%	22.05%	22.58%	80	18	17500	6
3-Nov	21.34	2.66	24.00	0.00	0.00	88.9%	18.57%	20.60%	80	18	17500	6
4-Nov	20.95	3.05	24.00	0.00	0.00	87.3%	17.58%	20.56%	80	18	17500	6
5-Nov	20.21	3.79	24.00	0.00	0.00	84.2%	20.11%	22.29%	80	18	17500	6
6-Nov	20.42	3.35	23.77	0.23	0.00	85.1%	23.57%	26.44%	80	18	17500	6
7-Nov	20.57	3.43	24.00	0.00	0.00	85.7%	17.00%	20.27%	80	18	17500	6
8-Nov	13.26	2.06	15.32	0.00	8.68	86.6%	14.63%	17.65%	80	18	17500	6
9-Nov	17.07	2.55	19.62	0.12	4.26	86.5%	4.00%	8.54%	80	18	17500	7
10-Nov	20.06	3.79	23.86	0.15	0.00	83.6%	1.75%	8.08%	80	18	17500	6
11-Nov	22.21	1.70	23.91	0.08	0.00	92.6%	1.80%	3.95%	80	18	17500	6
12-Nov	23.14	0.86	24.00	0.00	0.00	96.4%	1.77%	3.19%	80	18	17500	6
13-Nov	21.26	2.74	24.00	0.00	0.00	88.6%	1.75%	5.87%	80	18	17500	6
14-Nov	18.48	3.14	21.62	1.00	1.38	81.7%	1.80%	7.67%	80	18	17500	6
15-Nov	8.18	1.65	9.83	0.00	14.17	83.2%	1.85%	8.90%	80	18	17500	6
16-Nov	21.77	2.18	23.95	0.05	0.00	90.7%	1.80%	5.06%	80	18	17500	6
17-Nov	20.03	3.69	23.72	0.29	0.00	83.5%	2.56%	8.66%	80	18	17500	6
18-Nov	12.80	0.49	13.29	0.99	9.72	89.7%	2.26%	3.72%	60	15	17500	4
19-Nov	19.72	3.83	23.55	0.45	0.00	82.2%	6.65%	10.09%	80	18	17500	5
20-Nov	13.60	1.31	14.91	0.99	8.10	85.6%	1.80%	4.87%	80	18	17500	6
21-Nov	19.49	4.52	24.00	0.00	0.00	81.2%	2.60%	9.08%	80	18	17500	6
22-Nov	22.12	1.88	24.00	0.00	0.00	92.2%	1.79%	4.20%	80	18	17500	6
23-Nov	21.90	2.10	24.00	0.00	0.00	91.3%	5.36%	7.46%	80	18	17500	6
24-Nov	21.21	2.79	24.00	0.00	0.00	88.4%	1.91%	5.90%	80	18	17500	6
25-Nov	13.20	3.37	16.57	0.54	6.89	77.2%	2.27%	10.28%	80	18	17500	6
26-Nov	0.00	0.00	0.00	0.00	24.00	87.7%	6.91%	10.46%	79	17	17500	6
27-Nov	8.54	0.69	9.24	0.32	14.44	89.3%	2.56%	5.98%	80	18	17500	6
28-Nov	14.99	1.86	16.84	0.00	7.16	89.0%	1.91%	6.10%	80	18	17500	6
29-Nov	22.63	1.38	24.00	0.00	0.00	94.3%	1.78%	3.36%	80	18	17500	6
30-Nov	21.65	2.35	24.00	0.00	0.00	90.2%	1.80%	5.39%	80	18	17500	6
	18.20	2.33	20.53	0.17	3.29	87.7%	6.9%	10.46%				

11-01-2006



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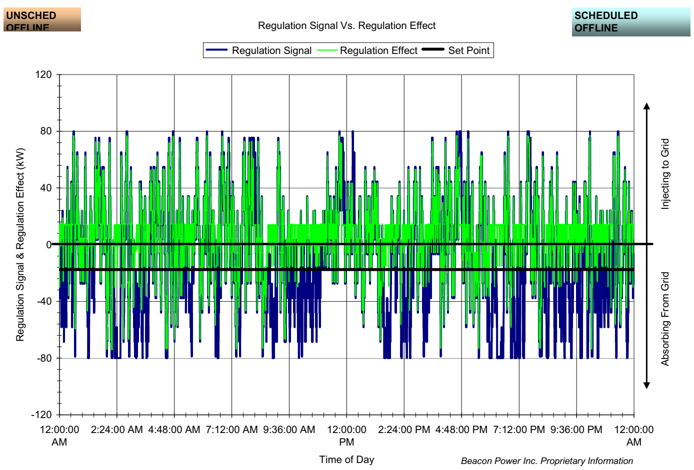

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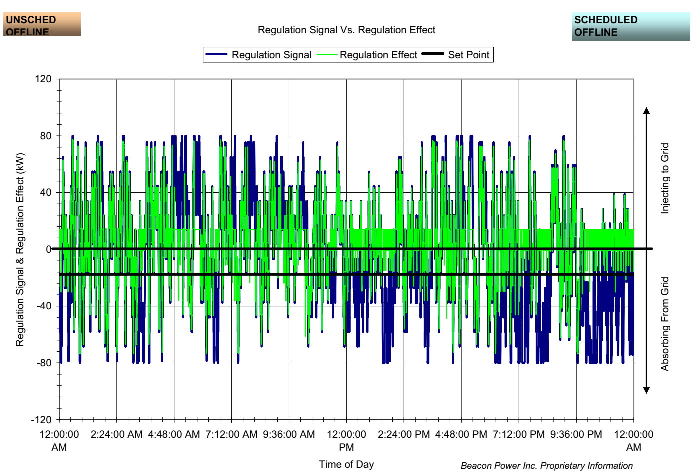

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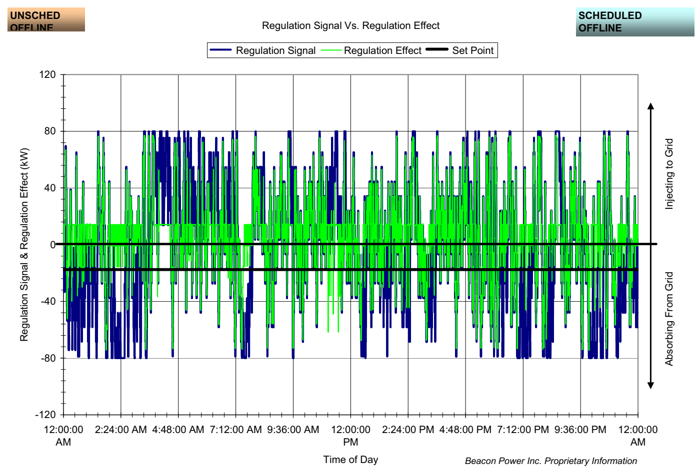

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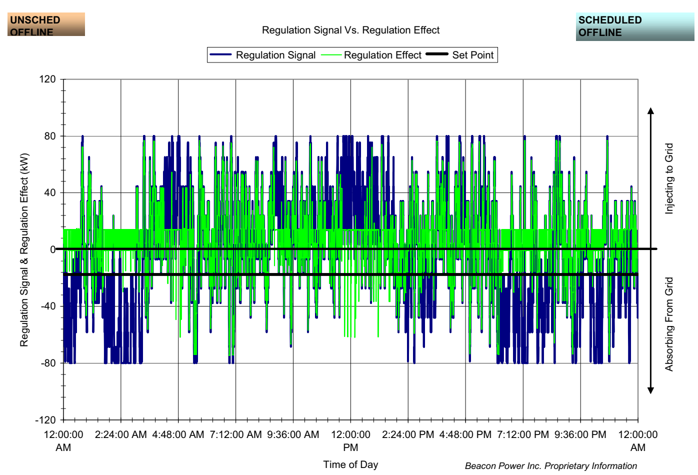

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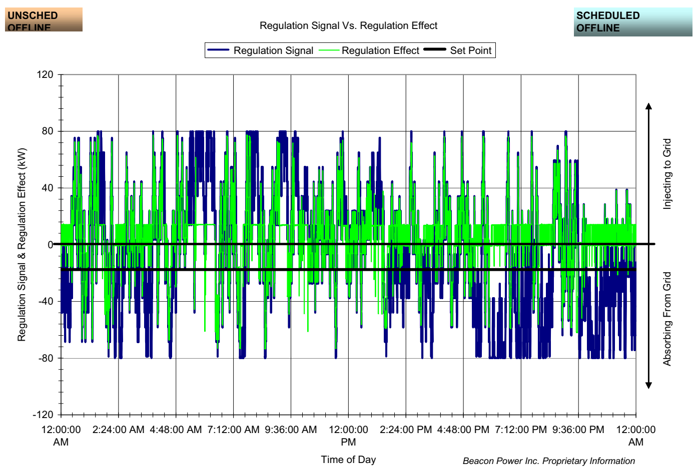

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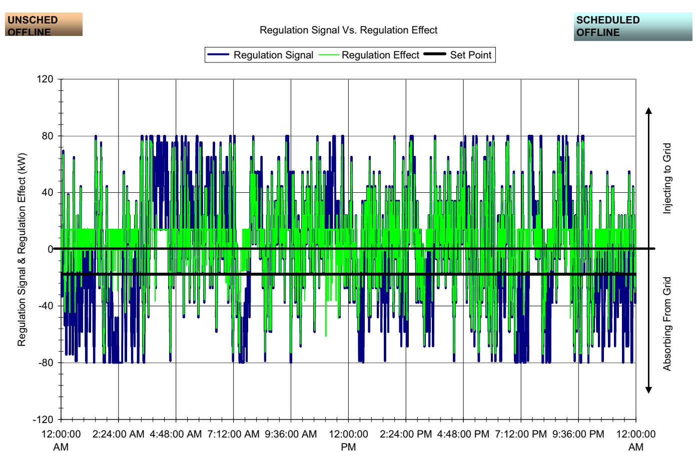

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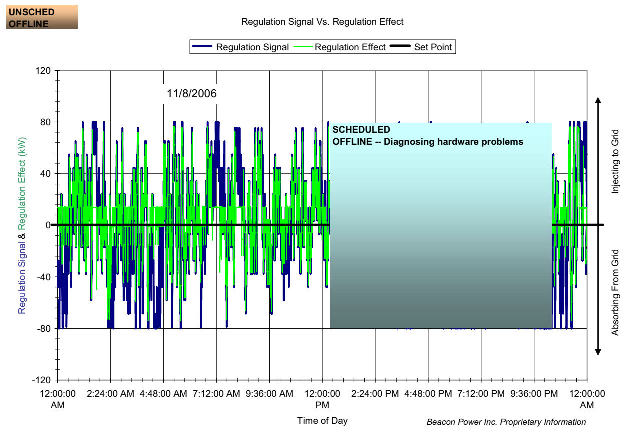

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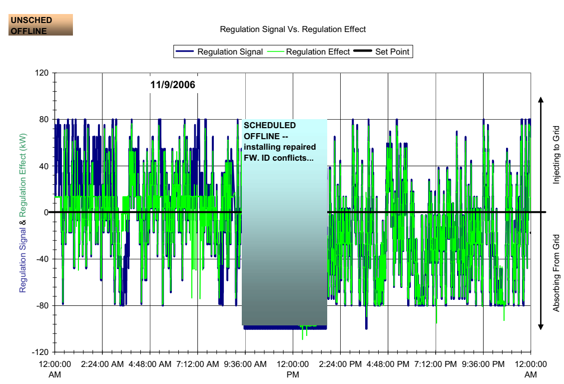

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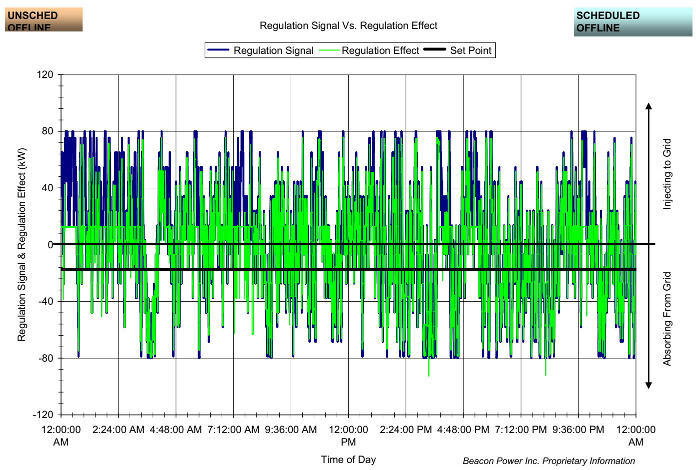

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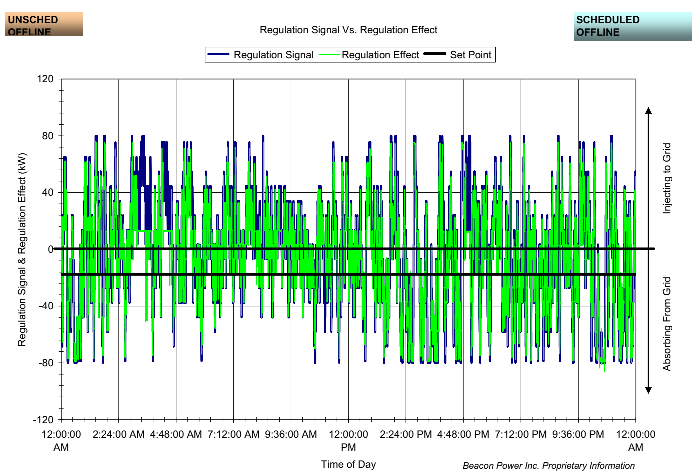

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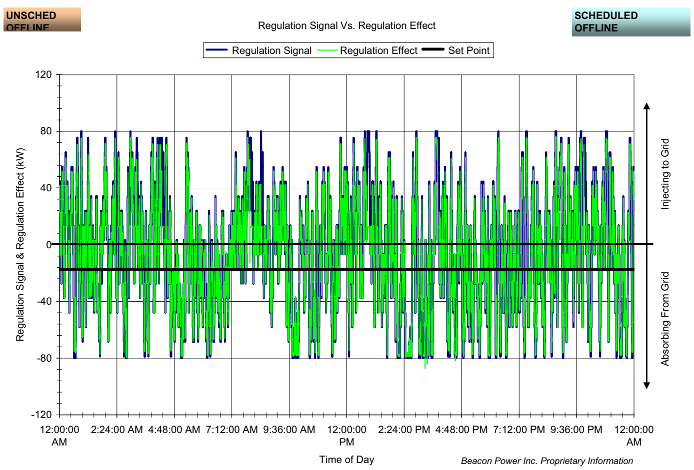

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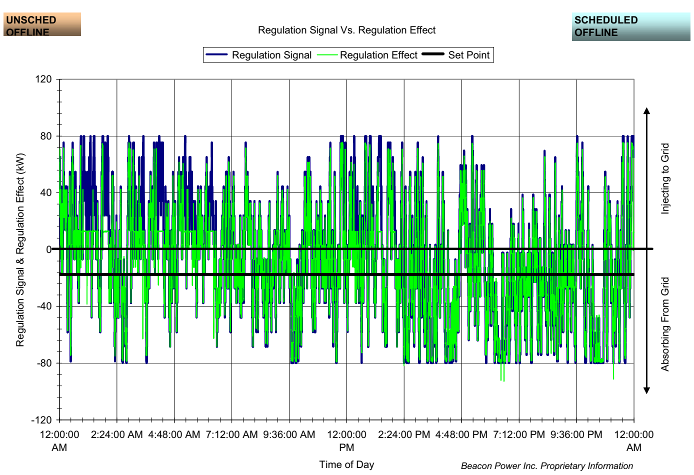

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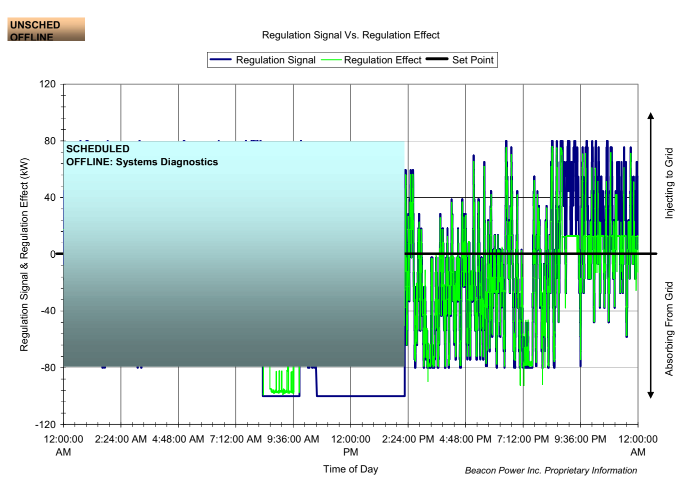

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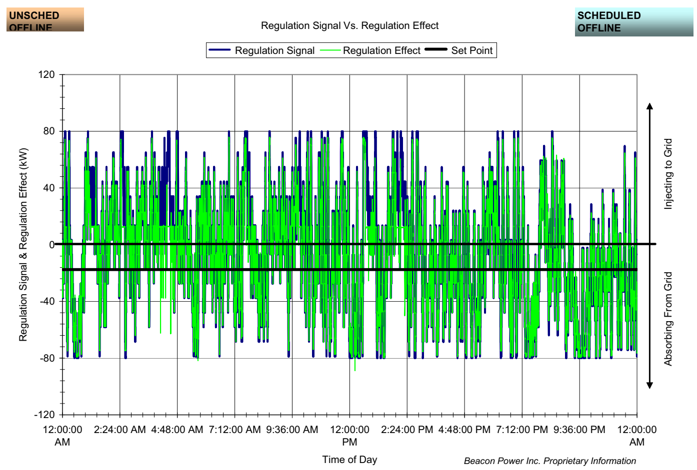

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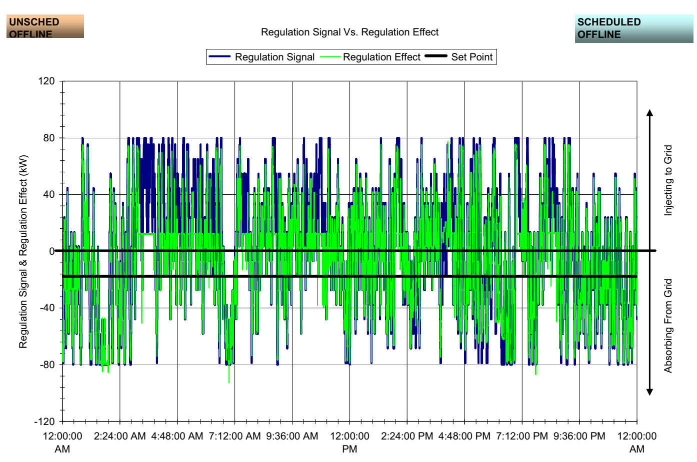

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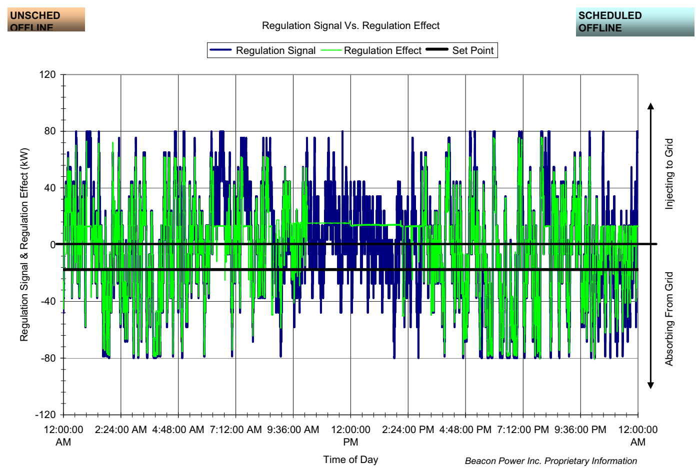

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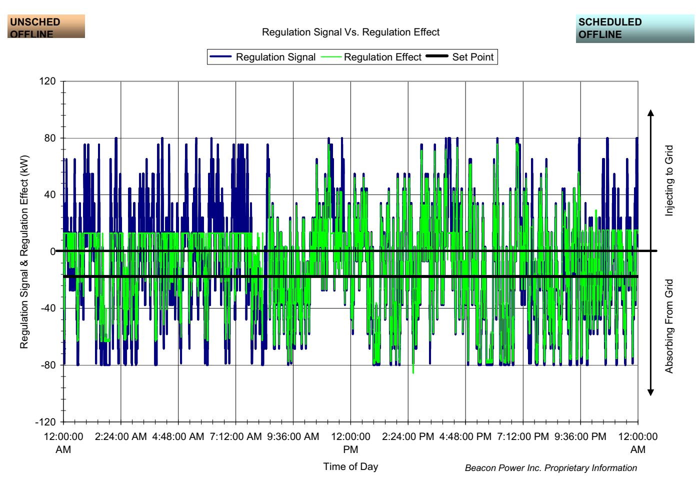

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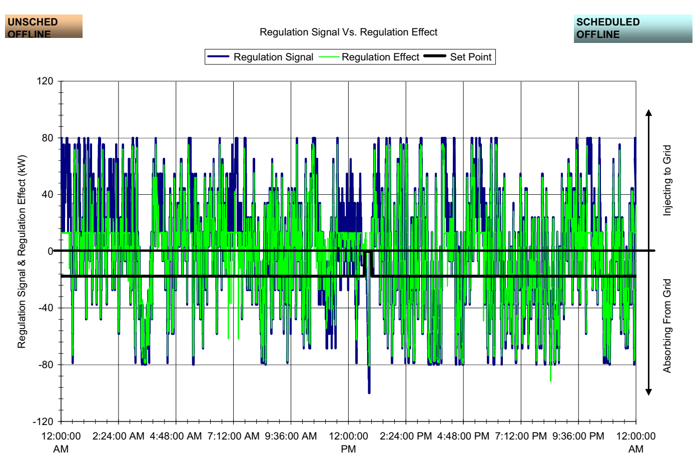

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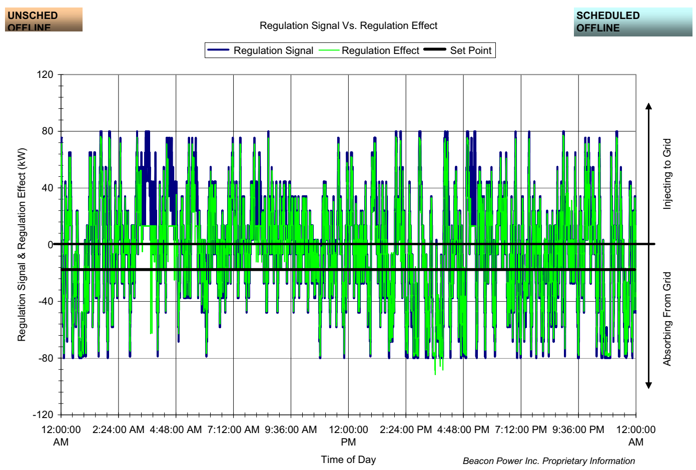

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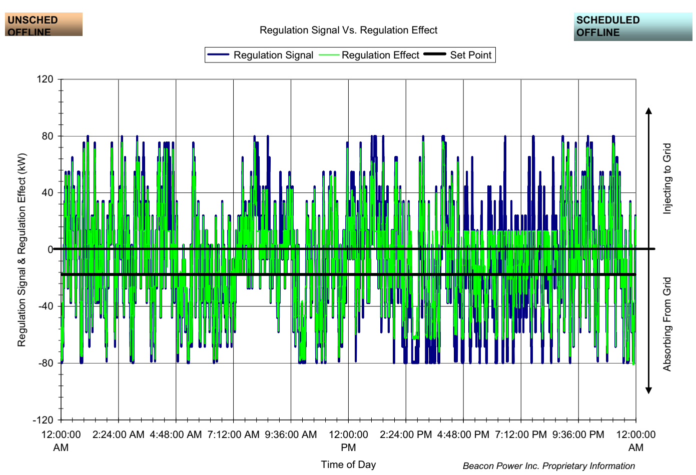

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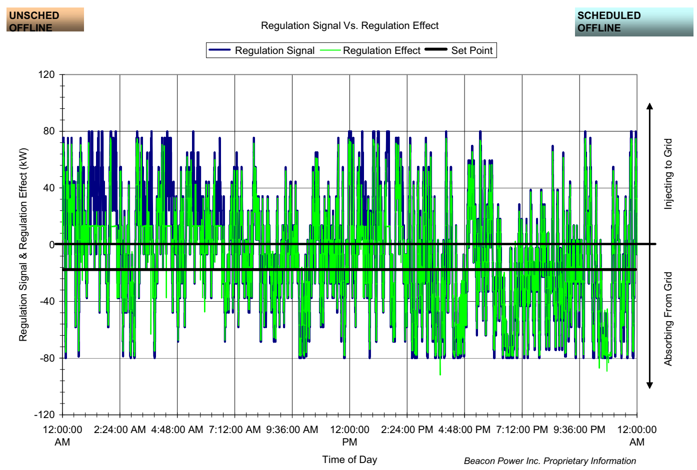

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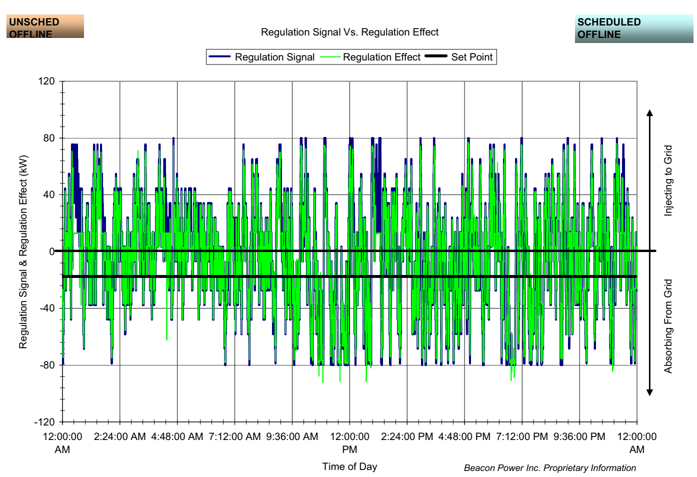

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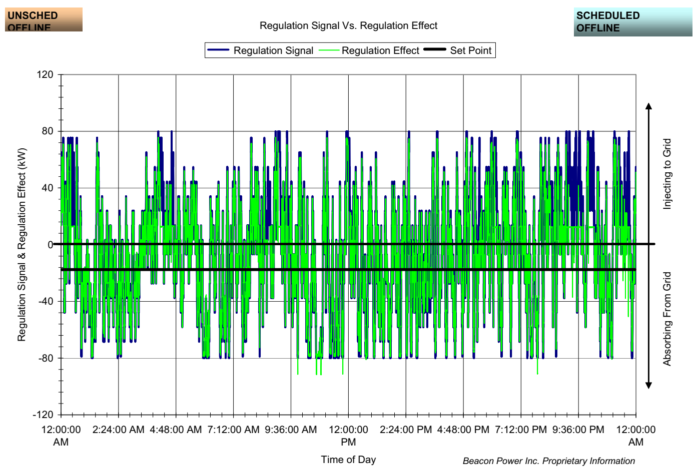
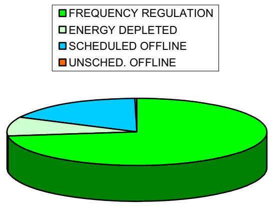


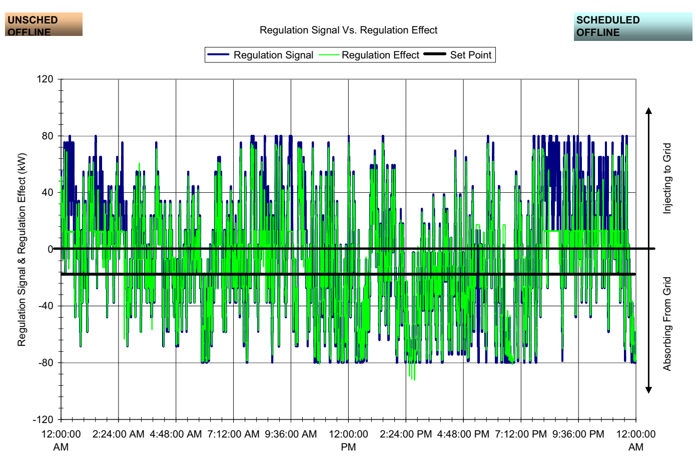
NYSERDA Run Data Monthly Summary Sheet **Date: December, 2006**

		Percent	Hours
DAILY SUMMARY	FREQUENCY REGULATION	73%	17.1
	ENERGY DEPLETED	9%	2.5
	SCHEDULED OFFLINE	18%	4.3
	UNSCHED. OFFLINE	0%	0.1
	Total	100%	24.0
ON-LINE PERFORMANCE	Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs	87.2%	
	Deviation Excluding Depleted Time	2.7%	
	Deviation Including Deplete Time	7.1%	



Date	Freq Reg	Energy Depleted	Total Online Hrs	Offline Unsched	Offline Sched	Avail	Deviation	Deviation w/ depletion	Max KW	Setpoint KW	Cutout Speed RPM	Max FW's
1-Dec	20.62	3.15	23.77	0.23	0.00	85.9%	2.04%	7.25%	80	18	17500	6
2-Dec	21.59	2.41	24.00	0.00	0.00	90.0%	2.38%	6.14%	80	18	17500	6
3-Dec	19.57	4.43	24.00	0.00	0.00	81.5%	2.02%	8.91%	80	18	17500	6
4-Dec	20.48	3.52	24.00	0.00	0.00	85.3%	2.17%	8.13%	80	18	17500	6
5-Dec	21.32	2.68	24.00	0.00	0.00	88.8%	2.21%	6.50%	80	18	17500	6
6-Dec	21.19	1.17	22.36	1.64	0.00	88.3%	1.93%	3.41%	80	18	17500	6
7-Dec	21.88	2.12	24.00	0.00	0.00	91.2%	1.86%	5.05%	80	18	17500	6
8-Dec	18.32	5.68	24.00	0.00	0.00	76.3%	14.00%	18.84%	80	18	17500	6
9-Dec	17.06	6.35	23.41	0.59	0.00	71.1%	6.94%	12.65%	80	18	17500	6
10-Dec	19.64	4.36	24.00	0.00	0.00	81.8%	2.39%	9.04%	80	18	17500	6
11-Dec	20.48	3.52	24.00	0.00	0.00	85.3%	2.60%	8.42%	80	18	17500	6
12-Dec	21.32	2.68	24.00	0.00	0.00	88.8%	2.68%	6.74%	80	18	17500	6
13-Dec	22.78	1.12	23.89	0.11	0.00	94.9%	1.86%	3.22%	80	18	17500	6
14-Dec	21.86	2.15	24.00	0.00	0.00	91.1%	1.81%	5.01%	80	18	17500	6
15-Dec	20.65	3.26	23.91	0.09	0.00	86.0%	1.89%	7.12%	80	18	17500	6
16-Dec	21.07	2.93	24.00	0.00	0.00	87.8%	2.16%	6.51%	80	18	17500	6
17-Dec	17.34	4.26	21.60	1.22	1.18	76.0%	1.92%	9.20%	80	18	17500	6
18-Dec	20.19	3.81	24.00	0.00	0.00	84.1%	1.94%	8.33%	80	18	17500	6
19-Dec	20.99	3.02	24.00	0.00	0.00	87.4%	1.86%	6.50%	80	18	17500	6
20-Dec	13.08	1.30	14.37	0.20	9.43	89.8%	2.04%	4.50%	80	18	17500	6
21-Dec	17.71	6.29	24.00	0.00	0.00	73.8%	1.77%	14.14%	80	0	17500	6
22-Dec	12.59	4.78	17.37	0.04	6.59	72.3%	3.57%	15.20%	80	0	17500	6
23-Dec	0.00	0.00	0.00	0.00	24.00	87.2%	2.74%	7.12%	76	0	17500	6
24-Dec	0.00	0.00	0.00	0.00	24.00	87.2%	2.74%	7.12%	76	0	17500	6
25-Dec	0.00	0.00	0.00	0.00	24.00	87.2%	2.74%	7.12%	76	0	17500	6
26-Dec	11.24	0.35	11.59	0.00	12.41	97.0%	2.81%	4.16%	60	15	17500	4
27-Dec	10.82	0.35	11.17	0.00	12.84	96.9%	2.11%	3.44%	60	15	17500	4
28-Dec	5.11	0.09	5.20	0.00	18.80	98.3%	1.03%	1.15%	80	15	17500	4
29-Dec	23.37	0.64	24.00	0.00	0.00	97.4%	1.96%	3.00%	60	15	17500	4
30-Dec	23.38	0.62	24.00	0.00	0.00	97.4%	1.98%	3.01%	60	15	17500	4
31-Dec	23.34	0.66	24.00	0.00	0.00	97.2%	2.79%	3.84%	60	15	17500	4
Averages for August	17.06	2.51	19.57	0.13	4.30	87.21%	2.74%	7.12%				

12-01-2006



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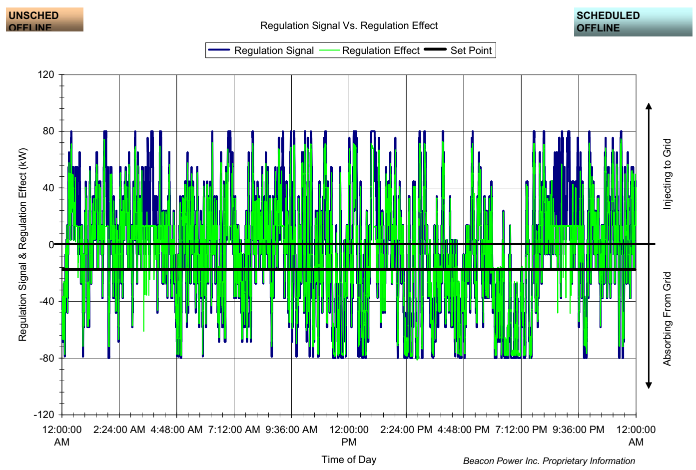

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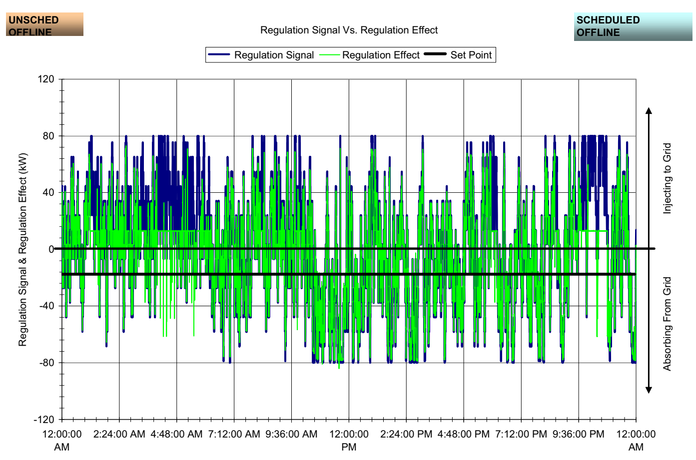

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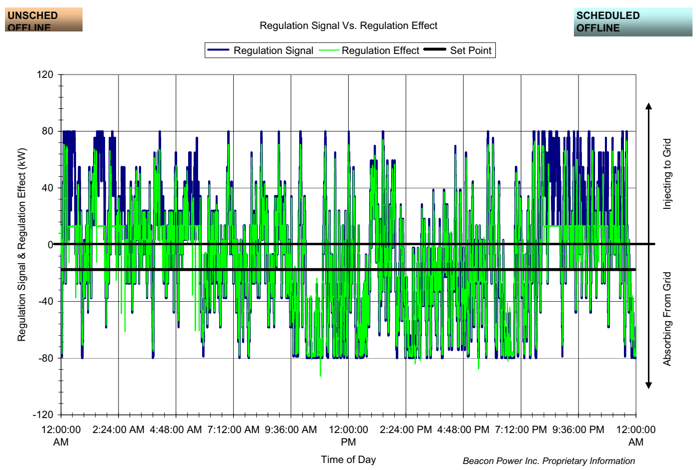

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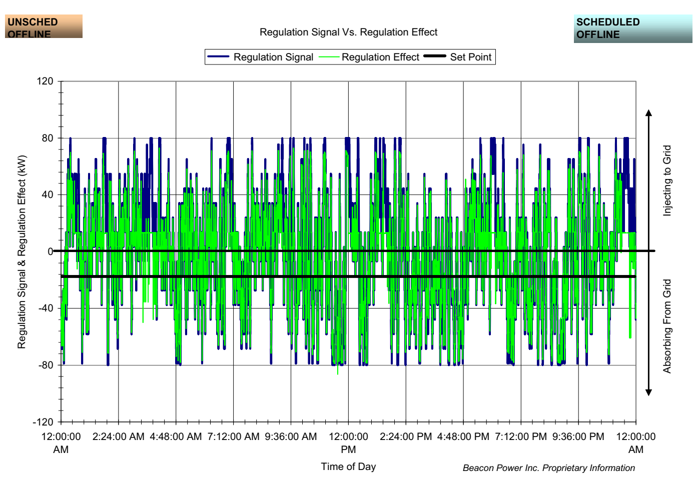

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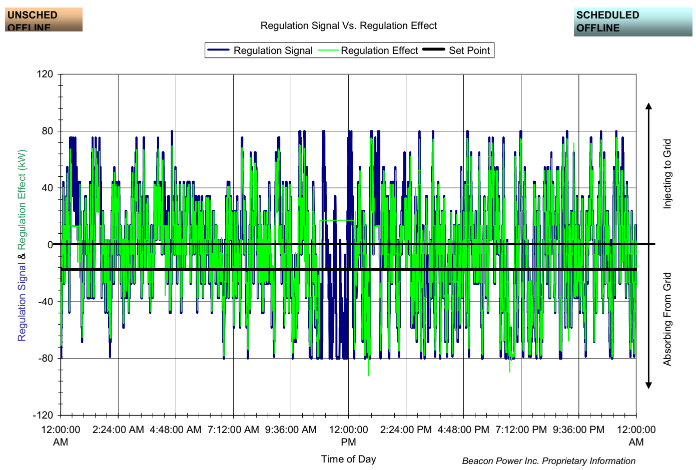

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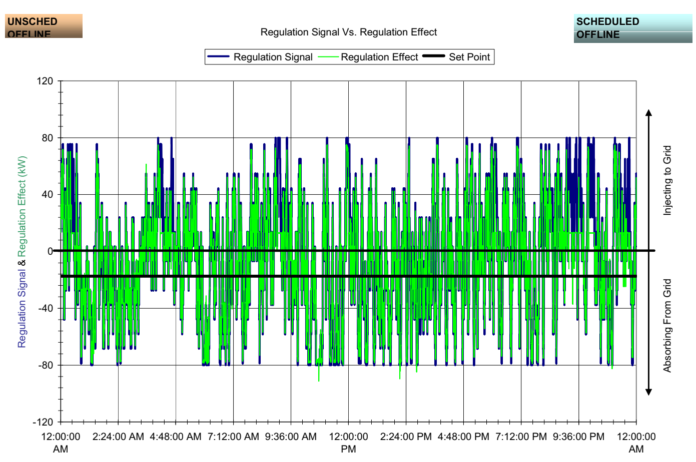

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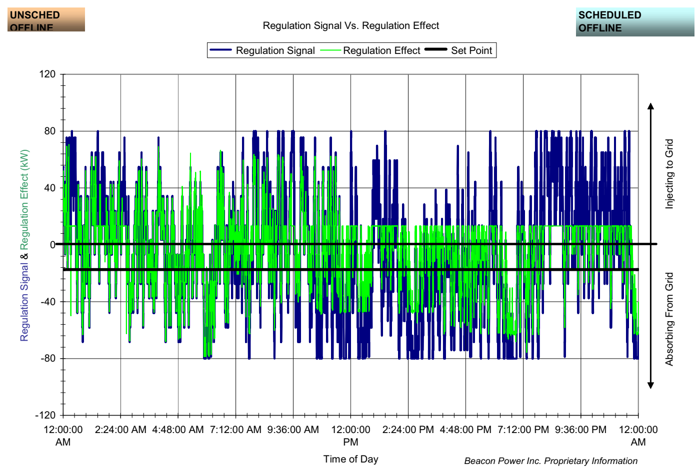

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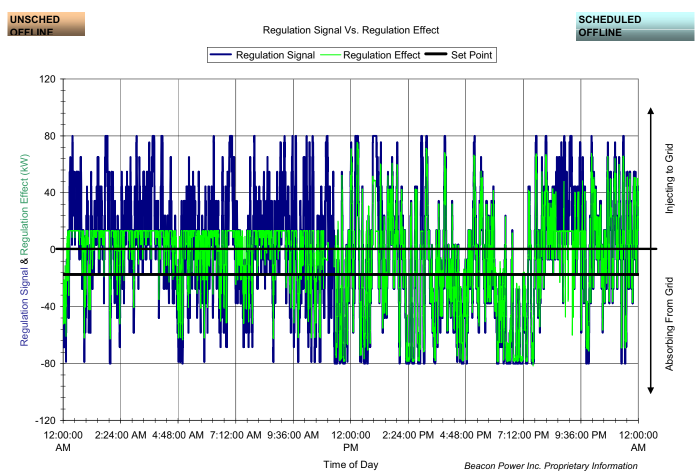

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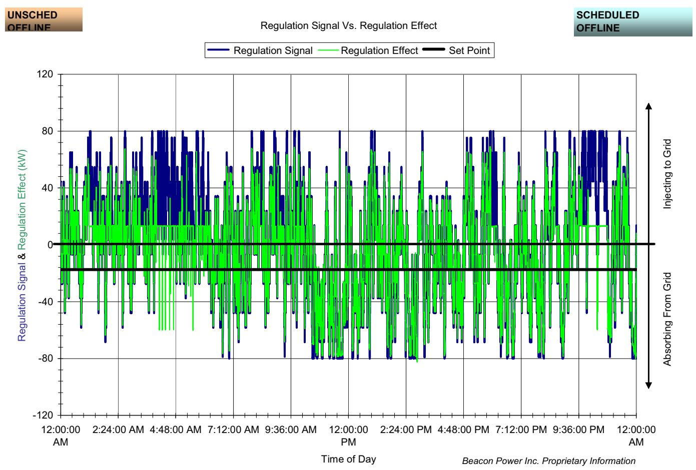

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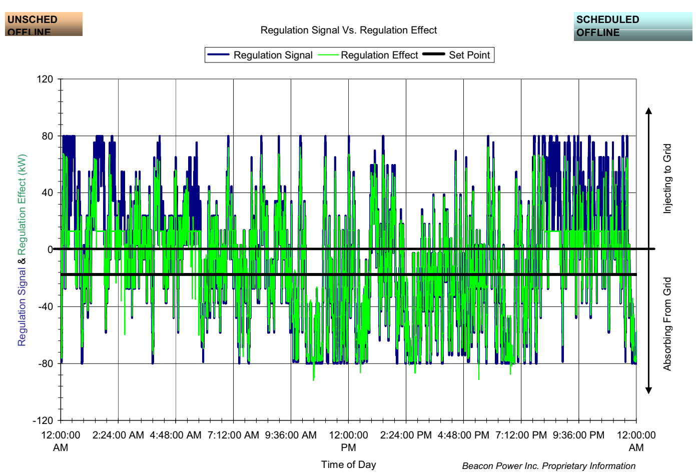

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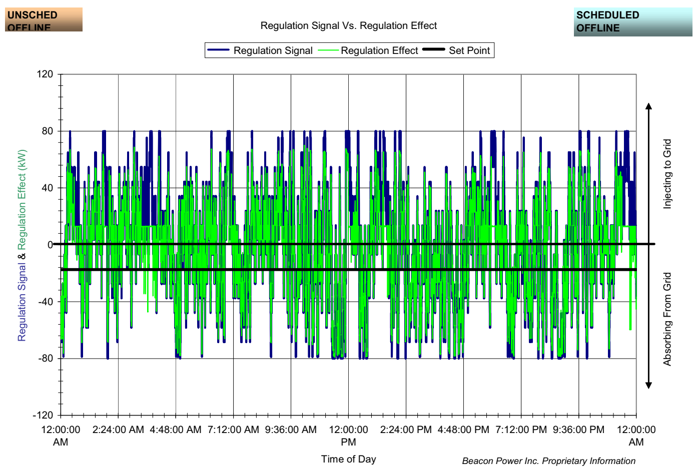

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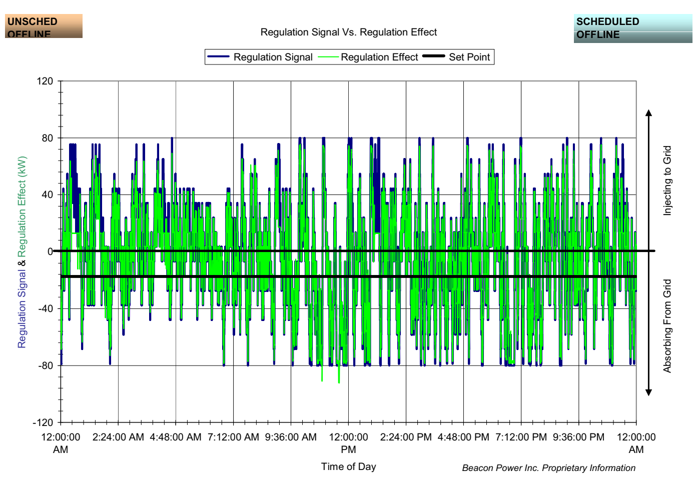

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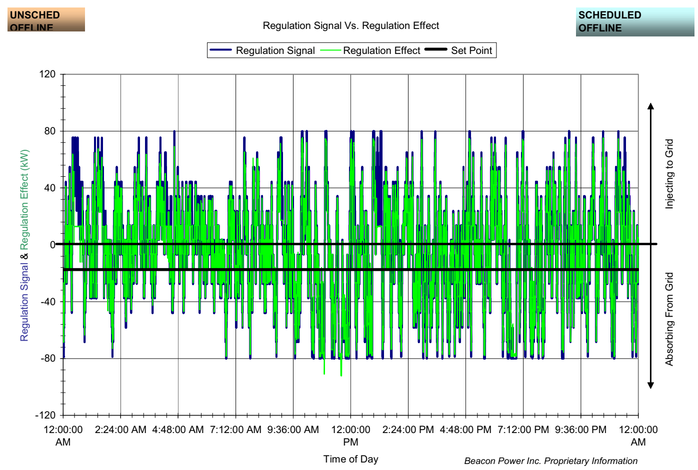

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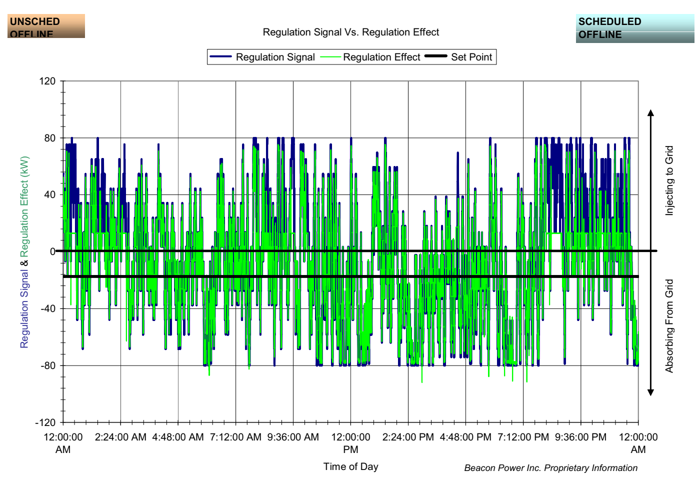

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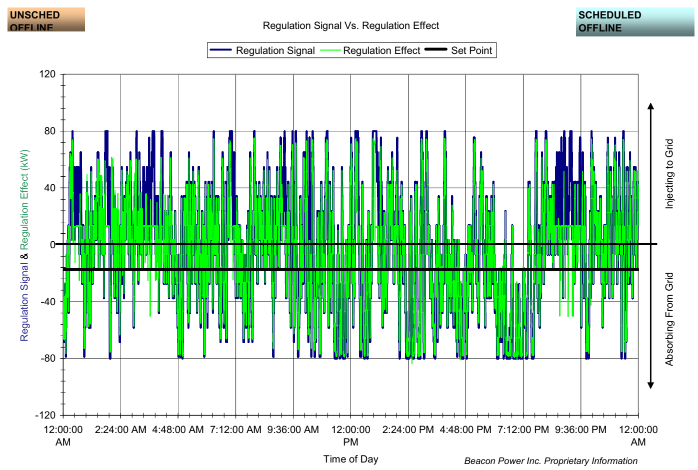

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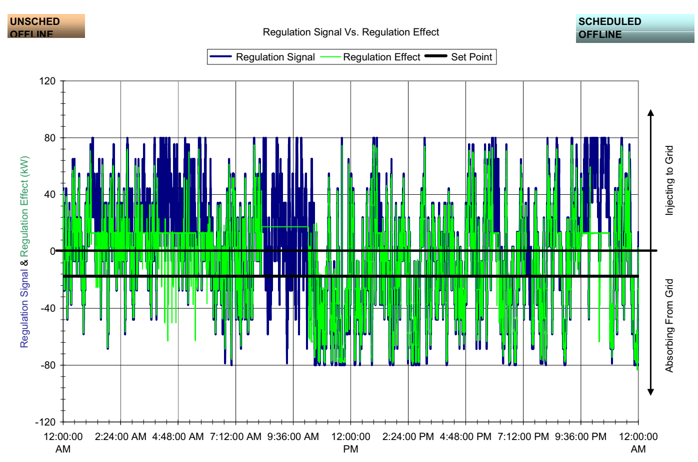

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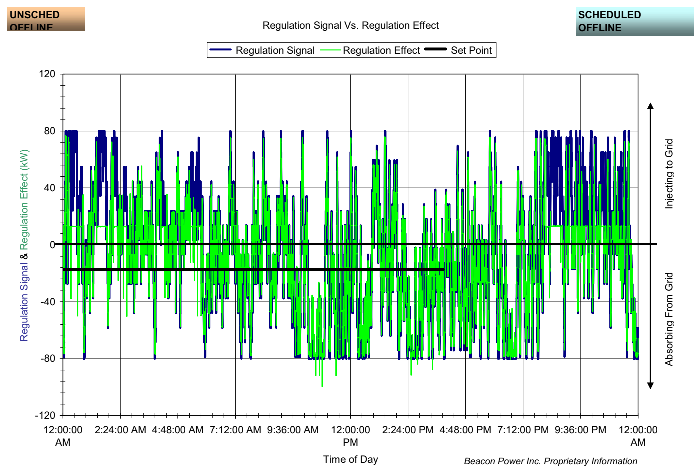

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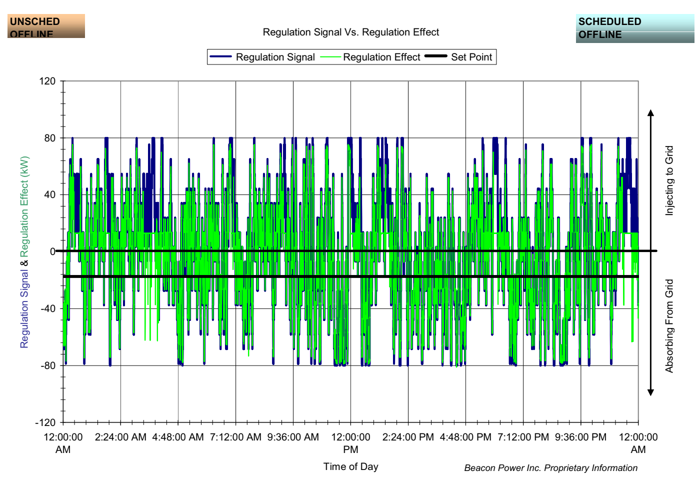

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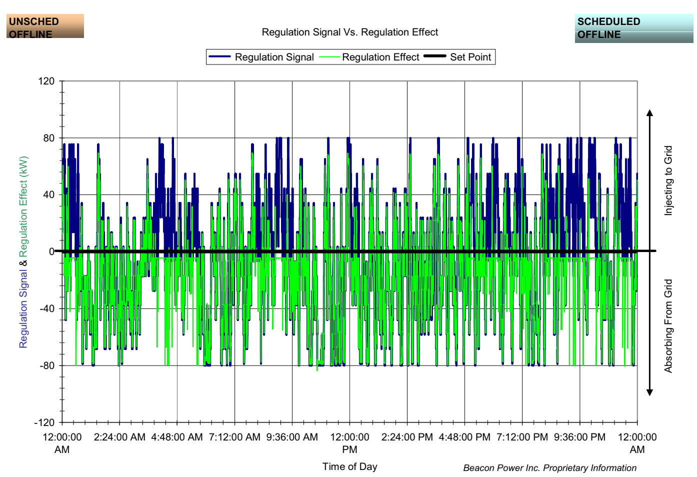

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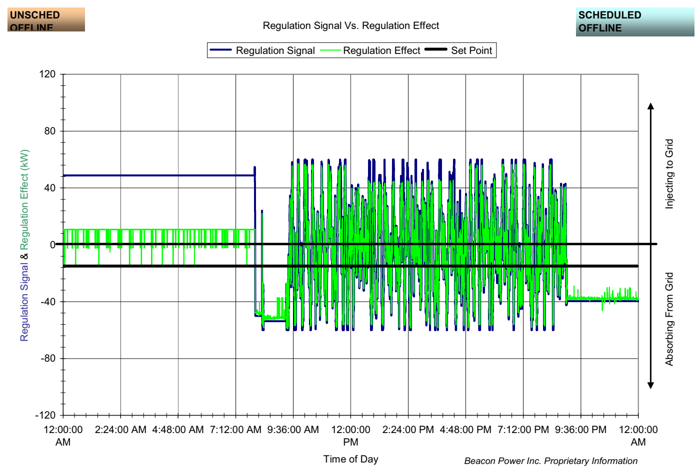

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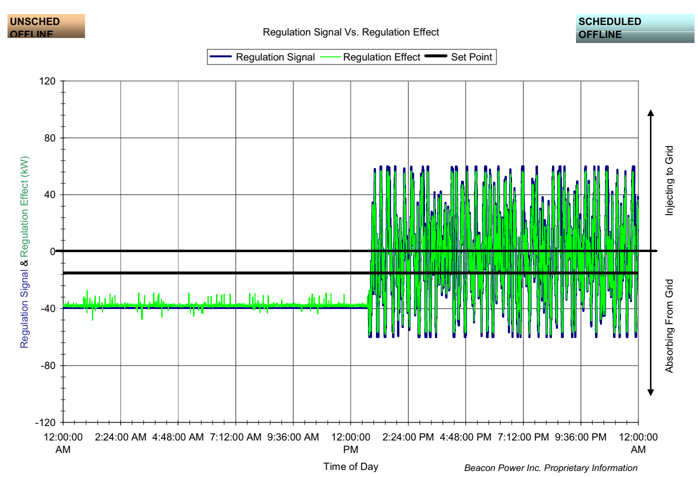

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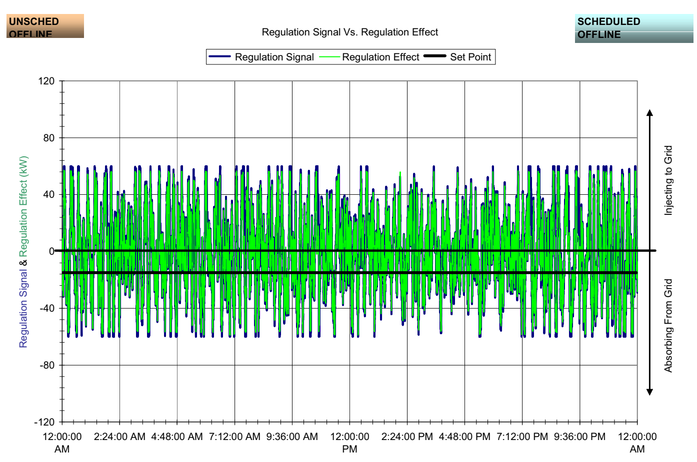

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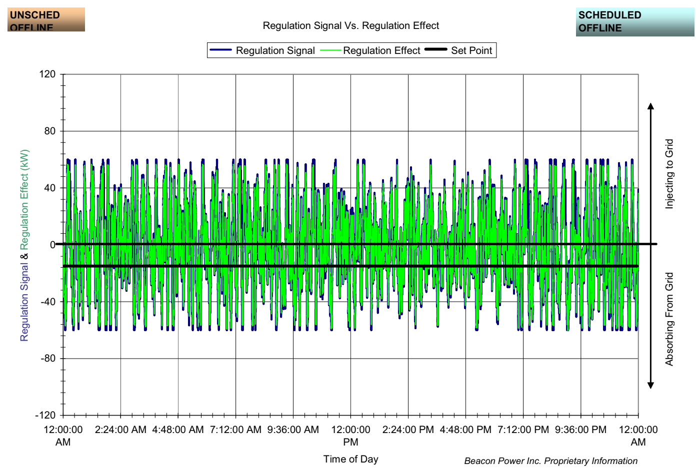

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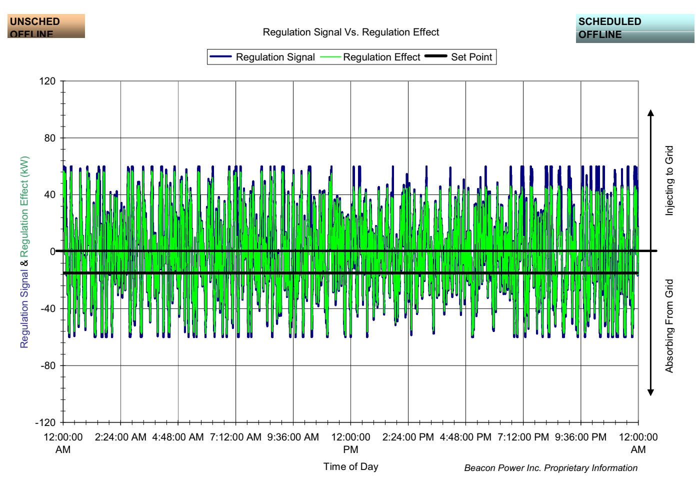
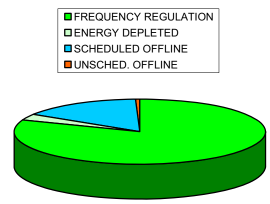


NYSERDA Run Data Monthly Summary Sheet **Date: January, 2007**

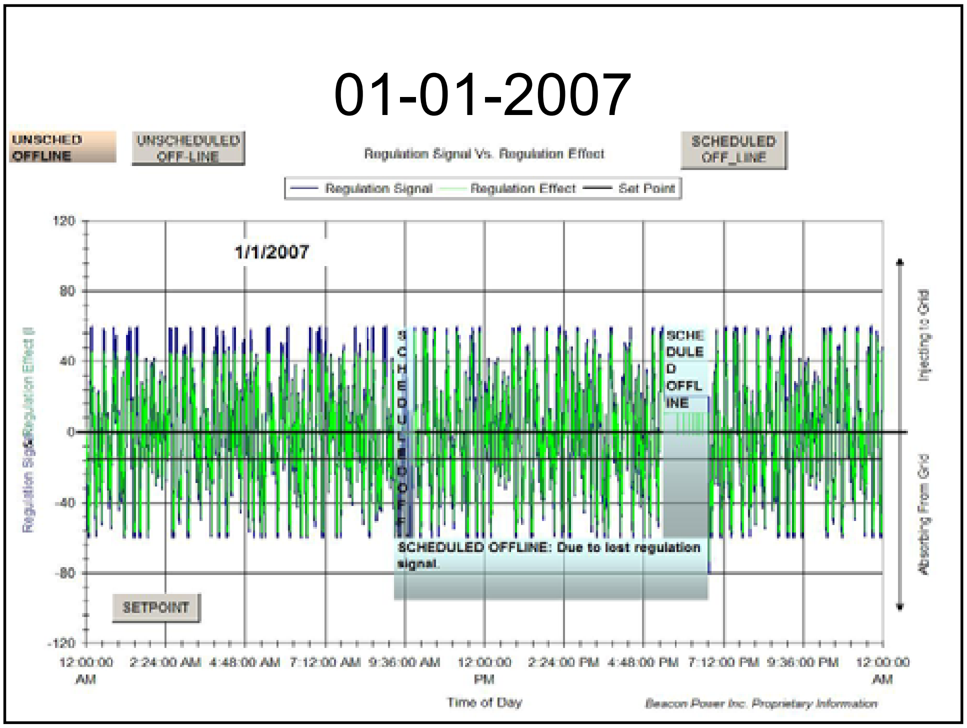
		Percent	Hours
DAILY SUMMARY	FREQUENCY REGULATION	81%	19.4
	ENERGY DEPLETED	3%	0.7
	SCHEDULED OFFLINE	15%	3.7
	UNSCHED. OFFLINE	1%	0.2
	Total	100%	24.0
ON-LINE PERFORMANCE	Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs	95.6%	
	Deviation Excluding Depleted Time	5.8%	
	Deviation Including Deplete Time	7.0%	

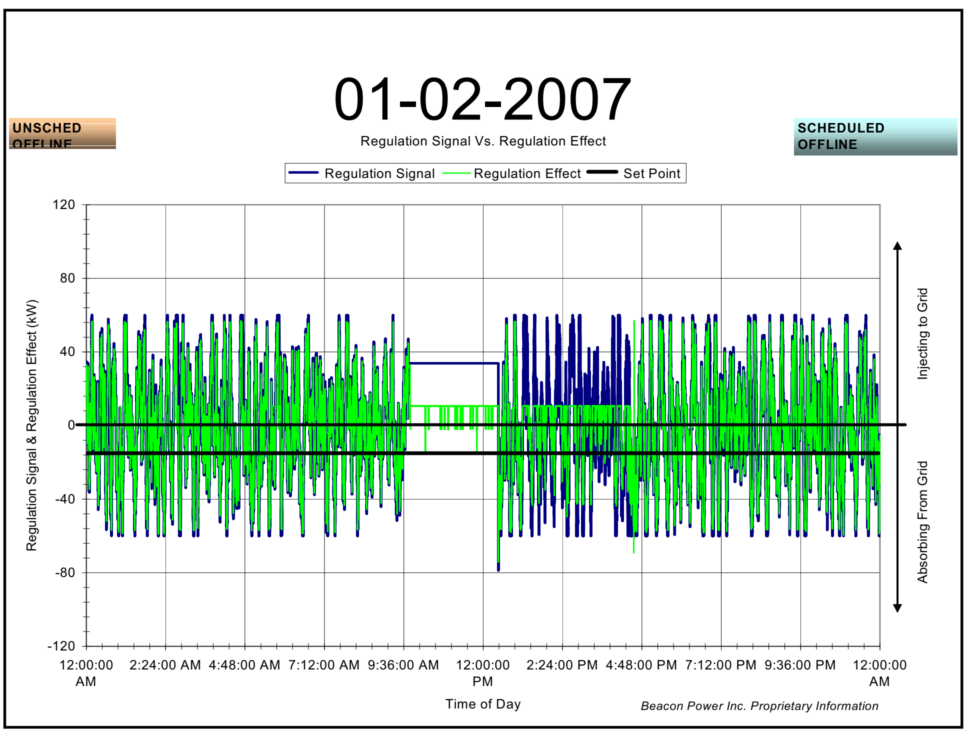


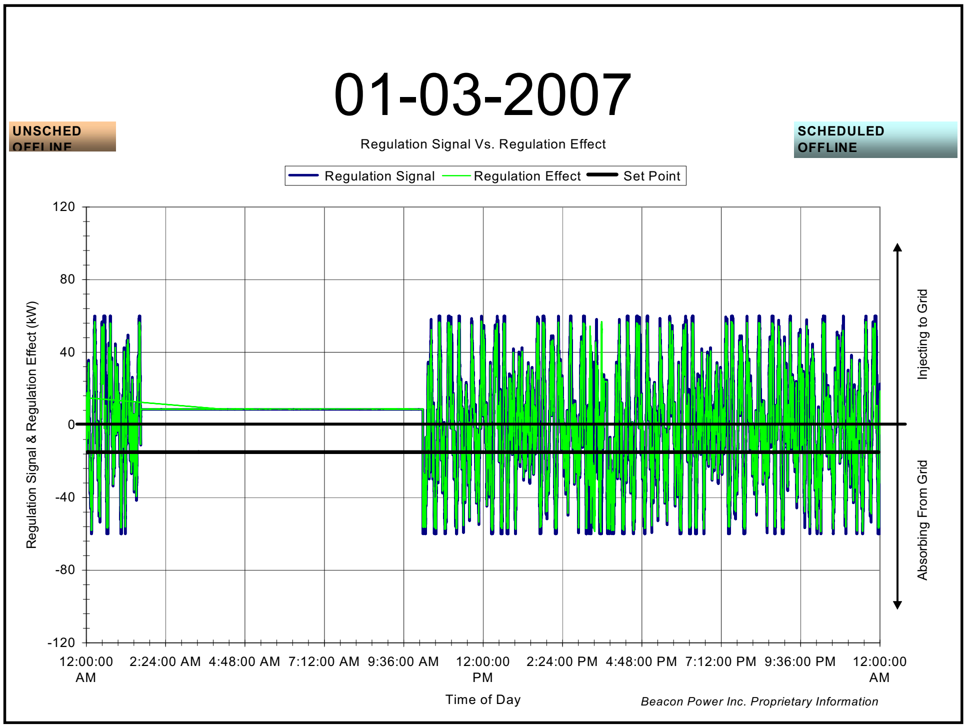
DAILY SUMMARY

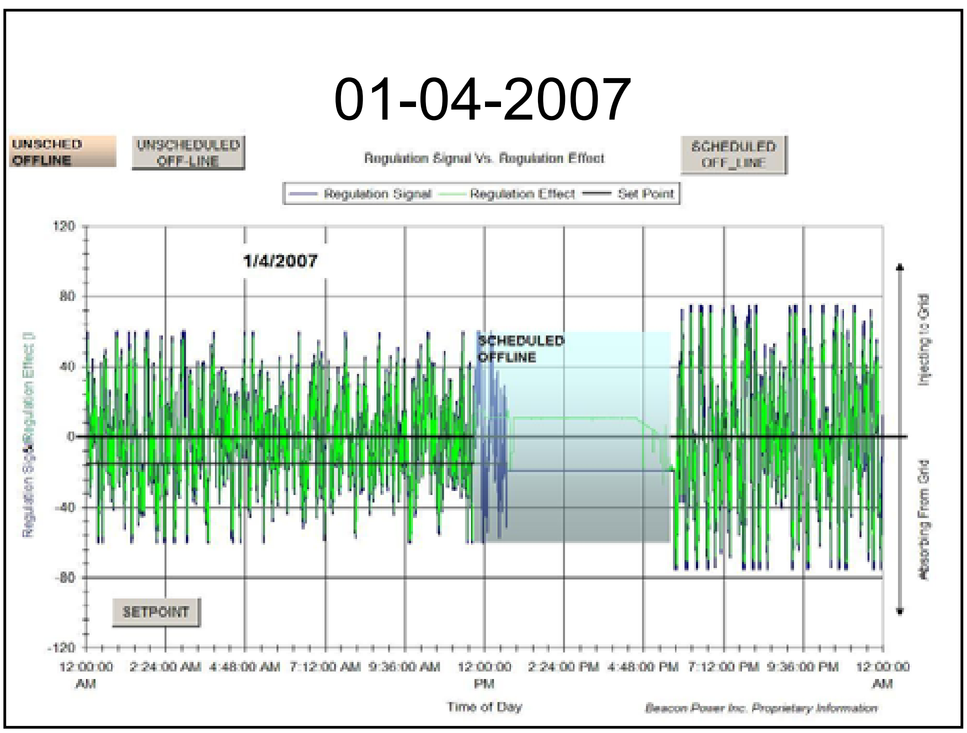
January 2007 NYSERDA SEM Performance Summary

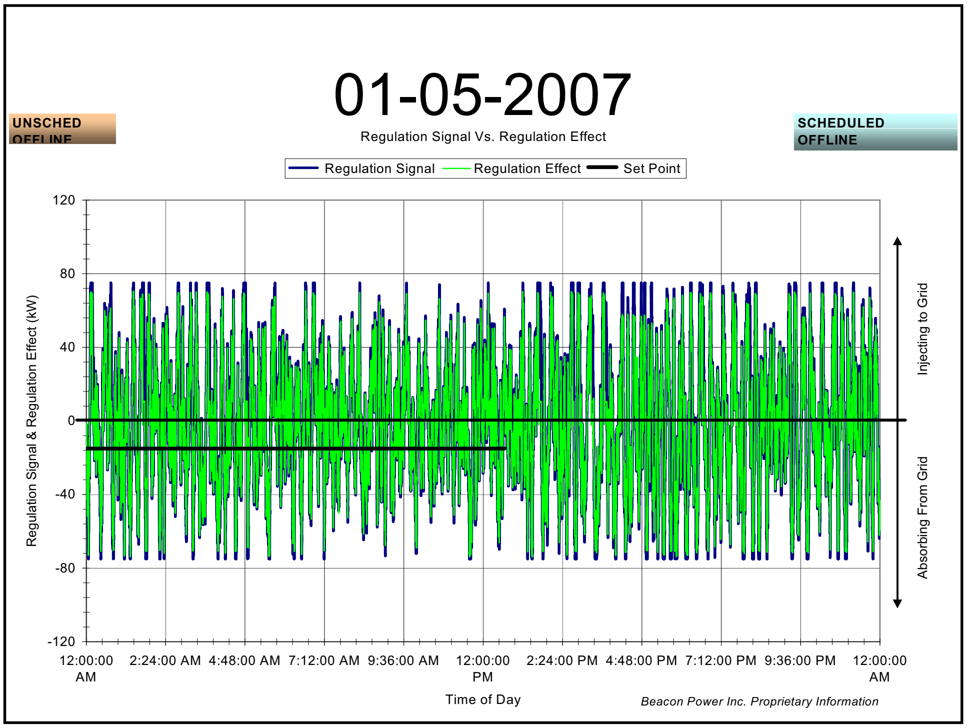
Date	Freq Reg	Energy Depleted	Total Online Hrs	Offline Unsched	Offline Sched	Avail	Deviation	Deviation w/ depletion	Max KW	Setpoint KW	Cutout Speed RPM	Max FW's
1-Jan	21.49	1.98	23.47	0.00	0.53	91.6%	2.98%	4.95%	60	15	17500	4
2-Jan	17.37	0.47	17.83	0.00	6.17	97.4%	2.06%	3.13%	60	15	17500	4
3-Jan	16.13	0.43	16.56	0.00	7.44	97.4%	3.48%	4.49%	60	15	17500	4
4-Jan	17.98	0.33	18.31	0.00	5.69	98.2%	1.61%	2.24%	75	15	17500	4
5-Jan	23.22	0.78	24.00	0.00	0.00	96.8%	2.01%	3.34%	75	15	17500	5
6-Jan	23.02	0.98	24.00	0.00	0.00	95.9%	2.11%	3.82%	75	15	17500	5
7-Jan	19.91	0.74	20.65	0.97	2.38	92.1%	2.18%	3.58%	75	15	17500	5
8-Jan	23.09	0.91	24.00	0.00	0.00	96.2%	2.24%	3.84%	75	15	17500	5
9-Jan	23.20	0.79	23.99	0.02	0.00	96.7%	2.10%	3.44%	75	15	17500	5
10-Jan	22.02	0.66	22.68	0.46	0.87	95.2%	2.14%	3.35%	75	15	17500	5
11-Jan	21.37	0.61	21.98	0.88	1.14	93.5%	1.91%	3.09%	75	15	17500	5
12-Jan	23.02	0.67	23.69	0.31	0.00	95.9%	1.93%	3.01%	75	15	17500	5
13-Jan	23.18	0.83	24.00	0.00	0.00	96.6%	2.15%	3.52%	75	15	17500	5
14-Jan	23.21	0.80	24.00	0.00	0.00	96.7%	1.96%	3.34%	75	15	17500	5
15-Jan	10.19	0.40	10.60	0.54	12.87	91.6%	3.63%	5.09%	75	15	17500	5
16-Jan	0.00	0.00	0.00	0.00	24.00	95.6%	0.00%	6.97%	80	15	17500	5
17-Jan	0.00	0.00	0.00	0.00	24.00	95.6%	0.00%	6.97%	80	15	17500	5
18-Jan	8.93	0.31	9.25	0.03	14.72	96.3%	7.88%	9.04%	75	15	17500	5
19-Jan	20.35	0.80	21.16	0.90	1.95	92.3%	10.00%	11.12%	75	15	17500	5
20-Jan	23.17	0.83	24.00	0.00	0.00	96.5%	10.88%	11.92%	75	15	17500	5
21-Jan	22.58	1.42	24.00	0.00	0.00	94.1%	13.56%	14.88%	75	15	17500	5
22-Jan	9.55	0.28	9.83	0.70	13.46	90.6%	10.86%	11.38%	75	15	17500	5
23-Jan	22.95	1.05	24.00	0.00	0.00	95.6%	15.24%	16.31%	75	15	17500	5
24-Jan	23.27	0.73	24.00	0.00	0.00	96.9%	9.45%	10.39%	75	15	17500	5
25-Jan	23.27	0.73	24.00	0.00	0.00	96.9%	9.67%	10.59%	75	15	17500	5
26-Jan	23.23	0.78	24.00	0.00	0.00	96.8%	10.03%	10.99%	75	15	17500	5
27-Jan	23.29	0.71	24.00	0.00	0.00	97.0%	9.62%	10.55%	75	15	17500	5
28-Jan	23.26	0.74	24.00	0.00	0.00	96.9%	9.51%	10.46%	75	15	17500	5
29-Jan	23.20	0.78	23.98	0.03	0.00	96.7%	10.25%	11.27%	75	15	17500	5
30-Jan	23.26	0.75	24.00	0.00	0.00	96.9%	5.05%	6.20%	75	15	17500	5
31-Jan	23.43	0.58	24.00	0.00	0.00	97.6%	1.86%	2.79%	75	15	17500	5
Averages for August	19.42	0.71	20.13	0.16	3.72	95.62%	5.81%	6.97%				


01-01-2007
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
1/1/2007
SCHEDULED OFFLINE
SETPOINT
SCHEDULED OFFLINE: Due to lost regulation signal.
Injecting to Grid
Absorbing From Grid
Time of Day
Beacon Power Inc. Proprietary Information

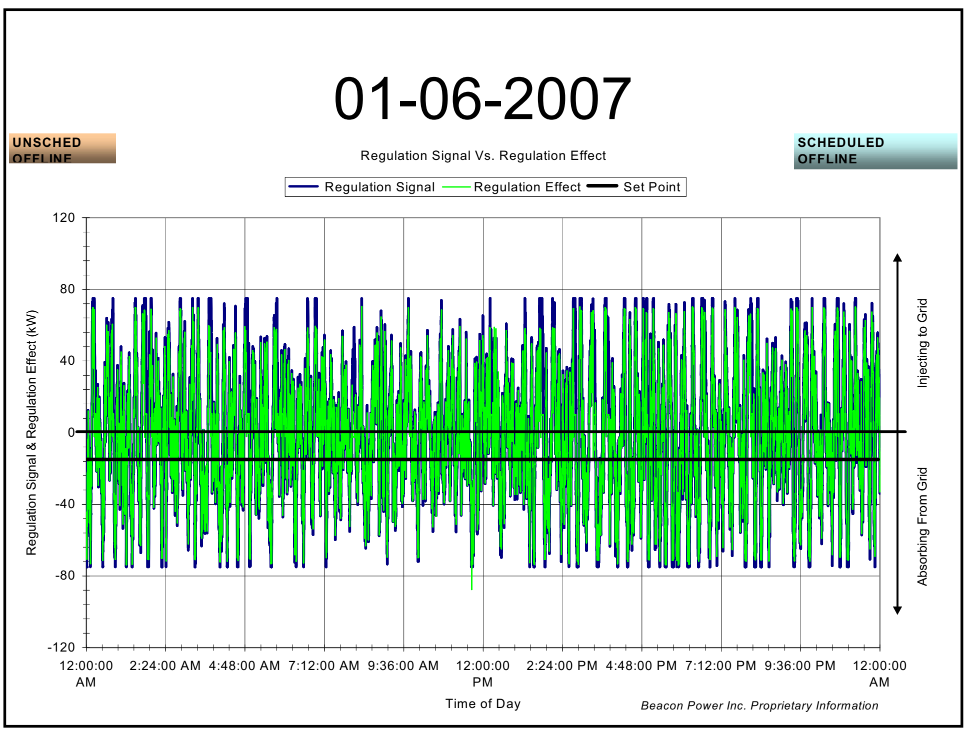

01-02-2007
UNSCHED OFFLINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Injecting to Grid
Absorbing From Grid
Time of Day
Beacon Power Inc. Proprietary Information


01-03-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Injecting to Grid
Absorbing From Grid
Beacon Power Inc. Proprietary Information


01-04-2007
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
1/4/2007
SCHEDULED OFFLINE
SETPOINT
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Injecting to Grid
Absorbing From Grid
Beacon Power Inc. Proprietary Information

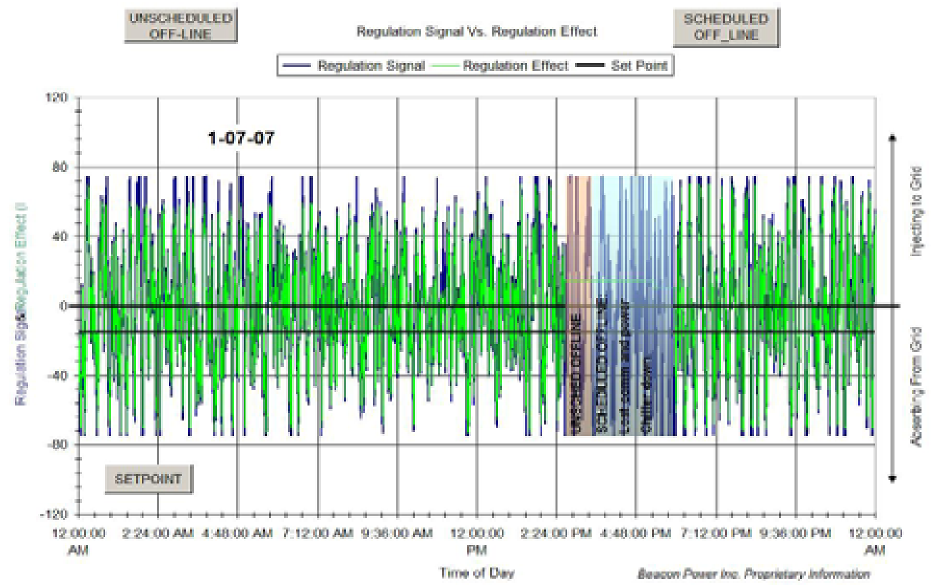


01-05-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

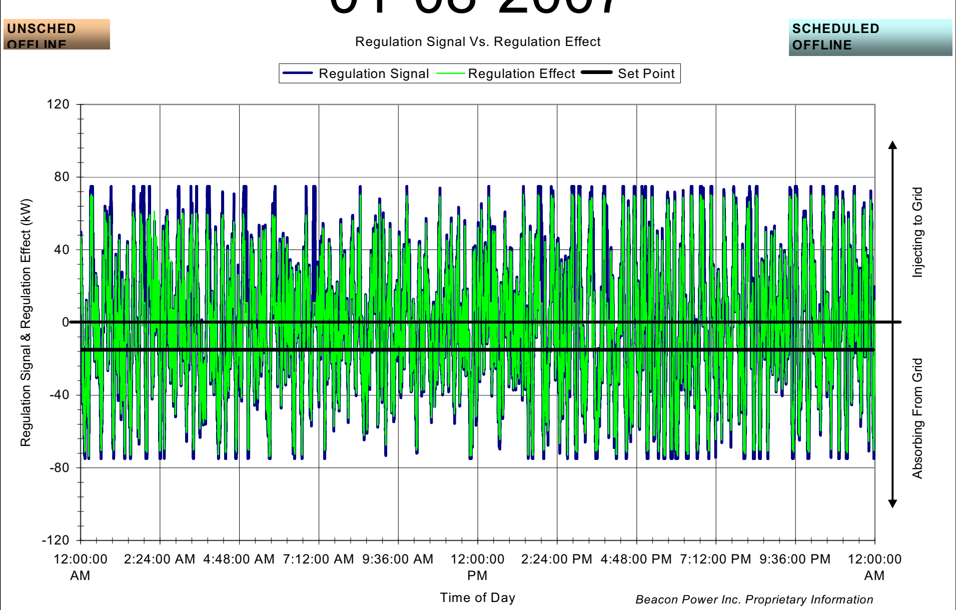


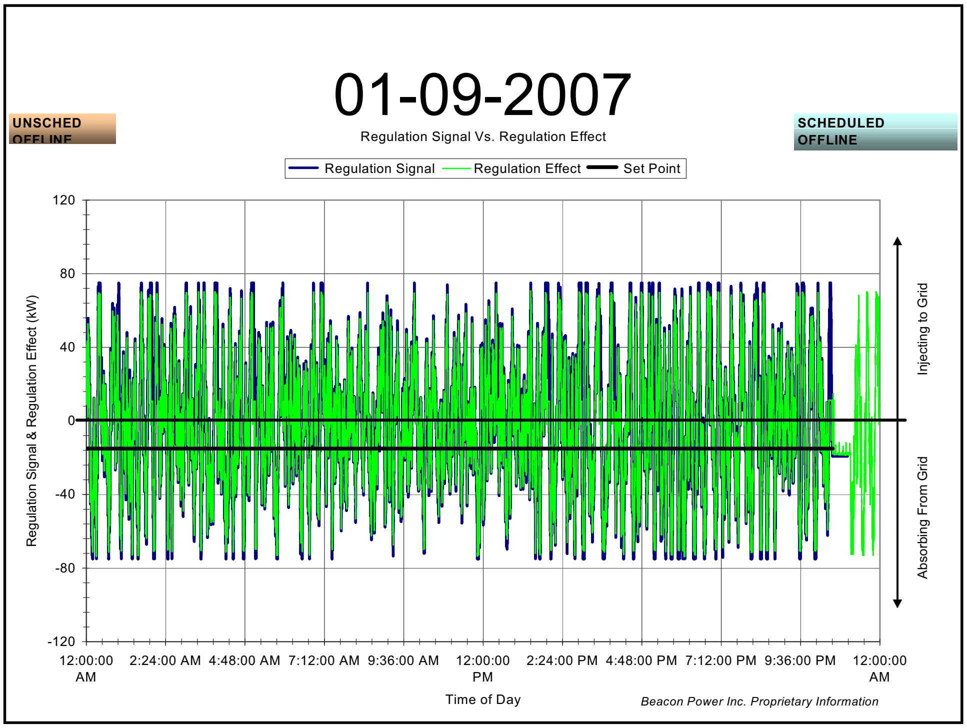
01-06-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

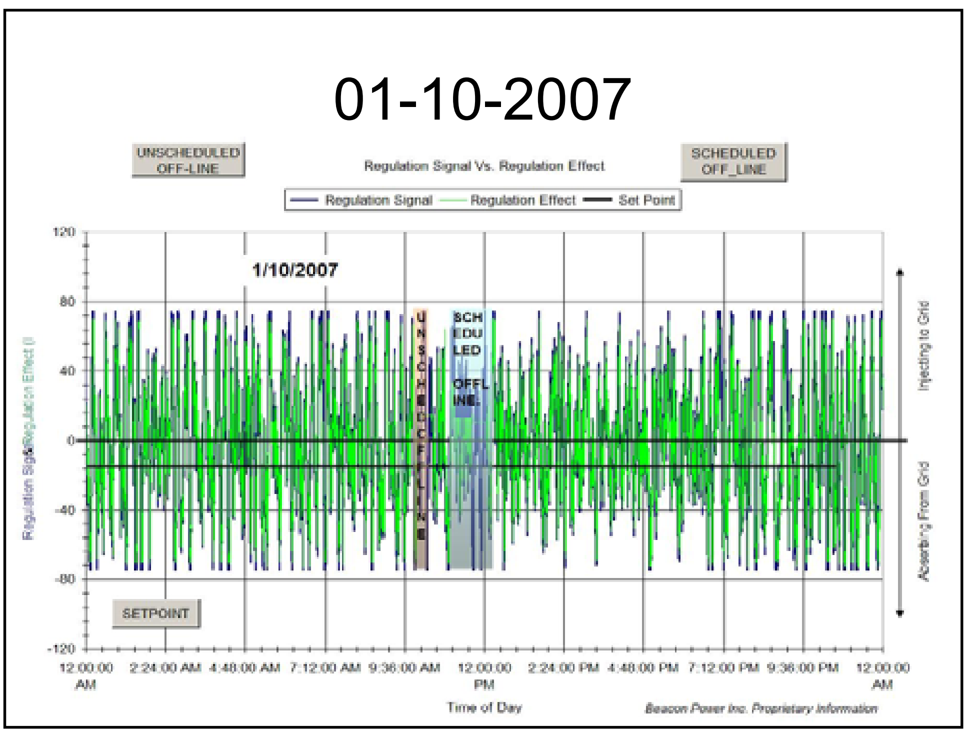
01-07-2007

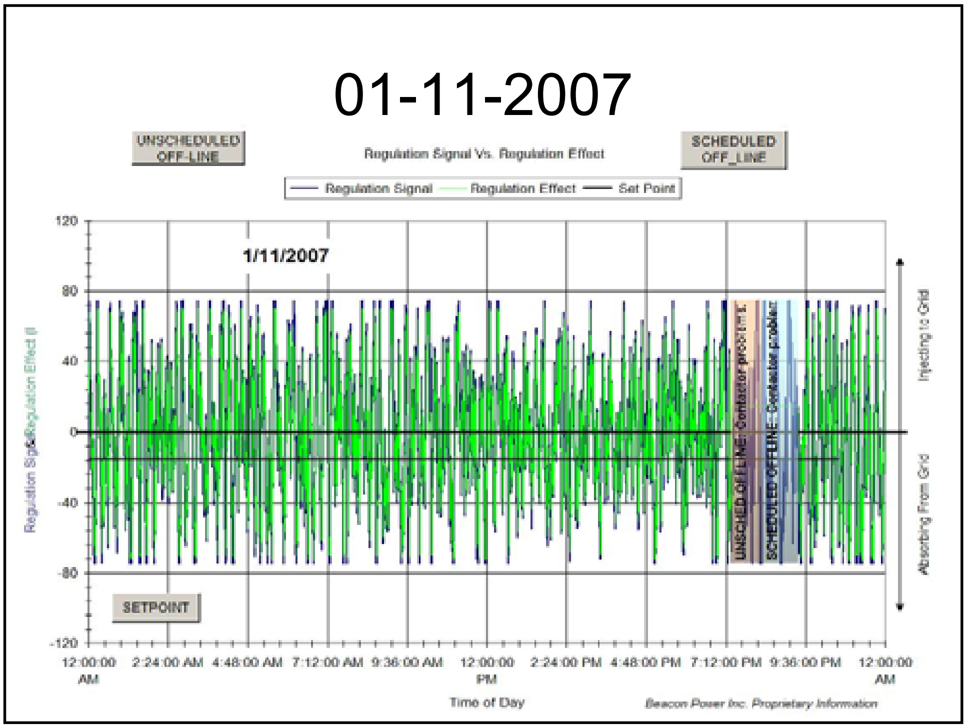


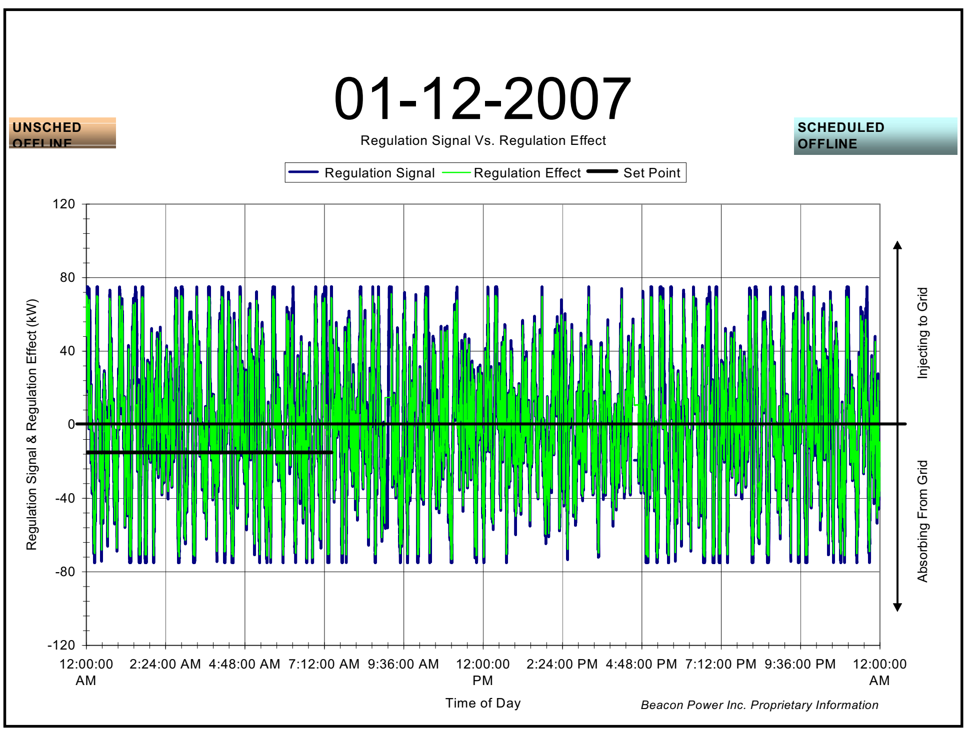
01-08-2007

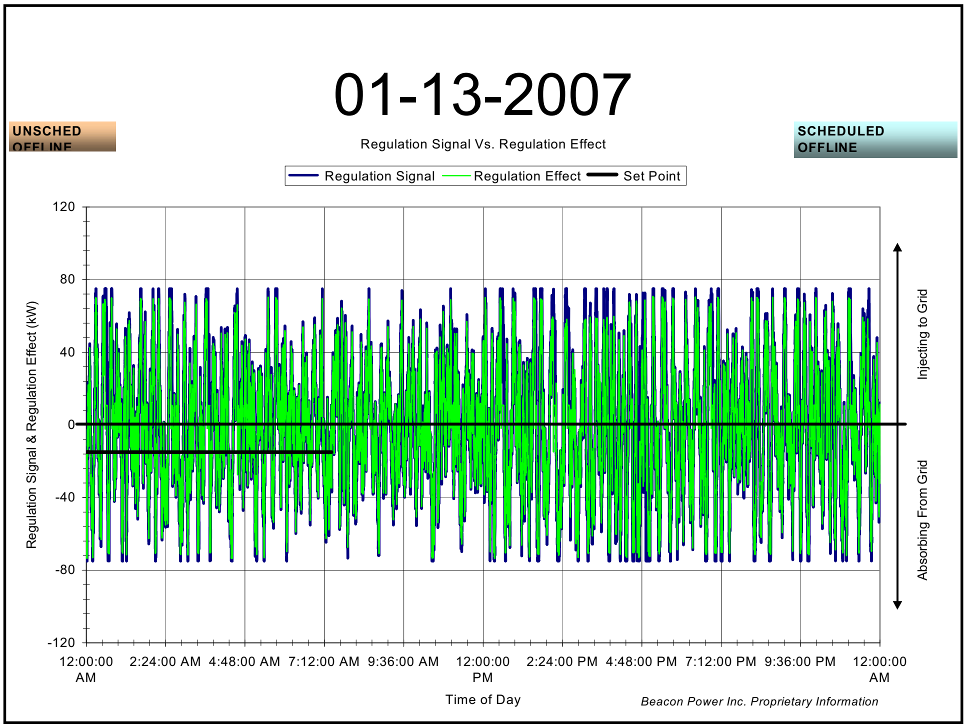


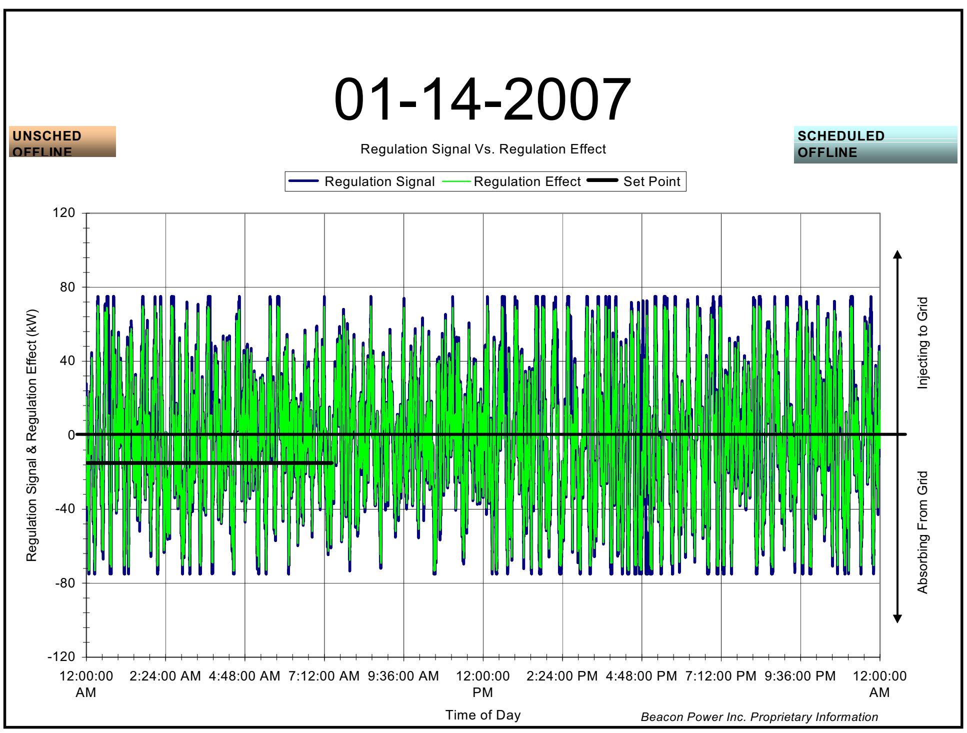

01-09-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

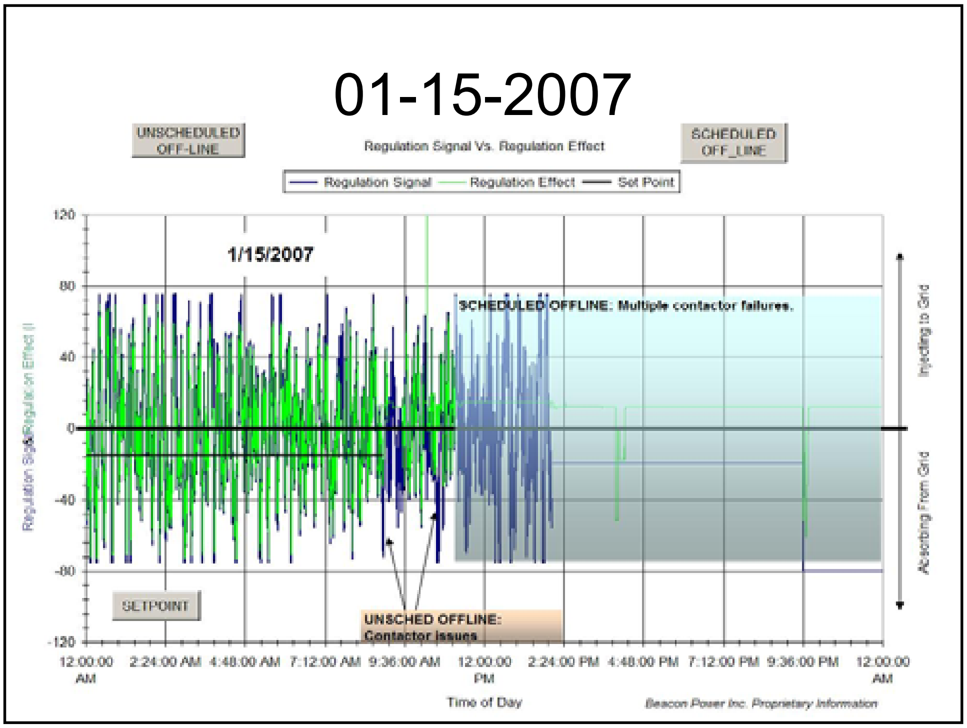

01-10-2007
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
1/10/2007
SETPOINT
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

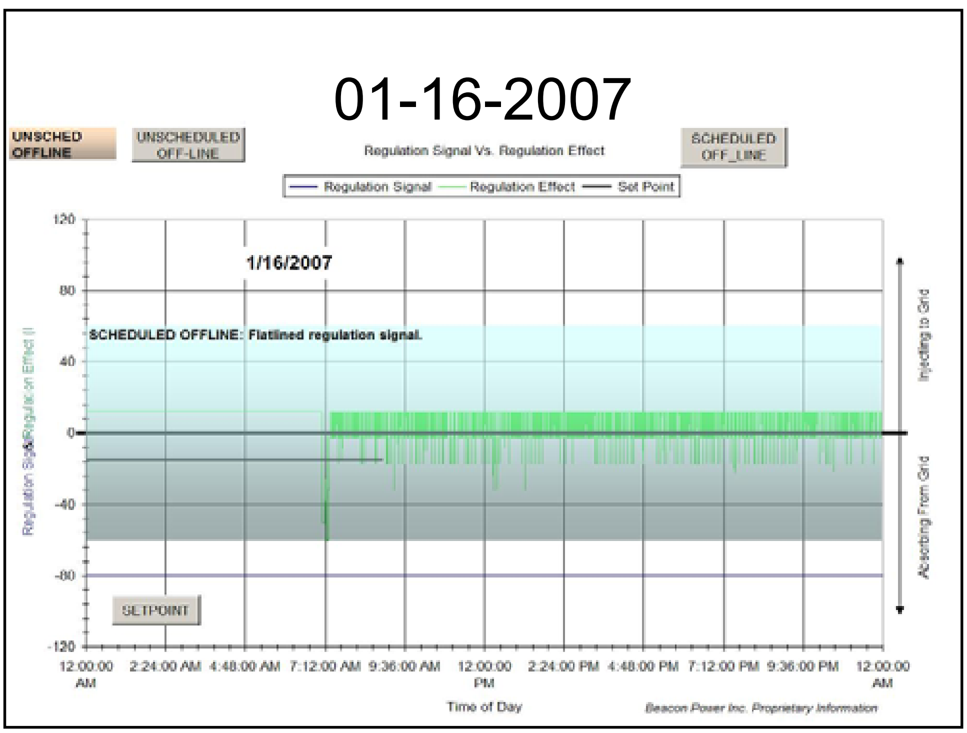

01-11-2007
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
1/11/2007
SETPOINT
Injecting to Grid
Absorbing From Grid
Time of Day
Beacon Power Inc. Proprietary Information


01-12-2007
UNSCHED OFFLINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
Time of Day
Beacon Power Inc. Proprietary Information

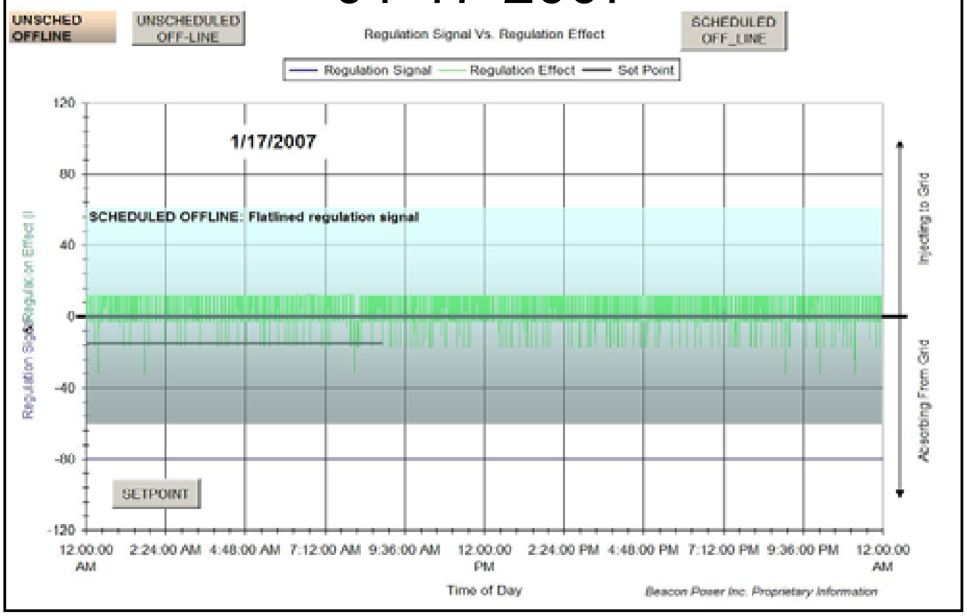

01-13-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information


01-14-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

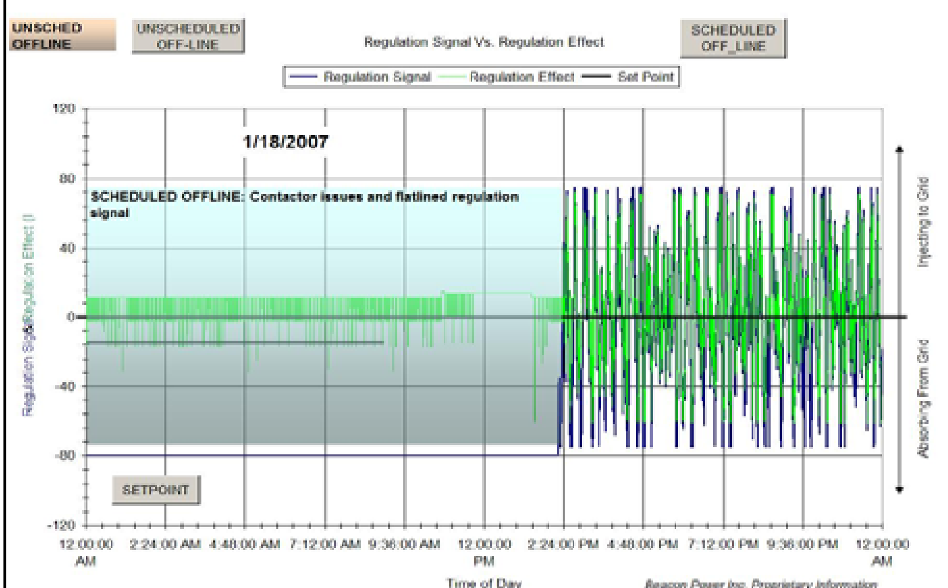

01-15-2007
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
1/15/2007
SCHEDULED OFFLINE: Multiple contactor failures.
Injecting to Grid
Absorbing From Grid
SETPOINT
UNSCHED OFFLINE: Contactor issues
Time of Day
Beacon Power Inc. Proprietary Information

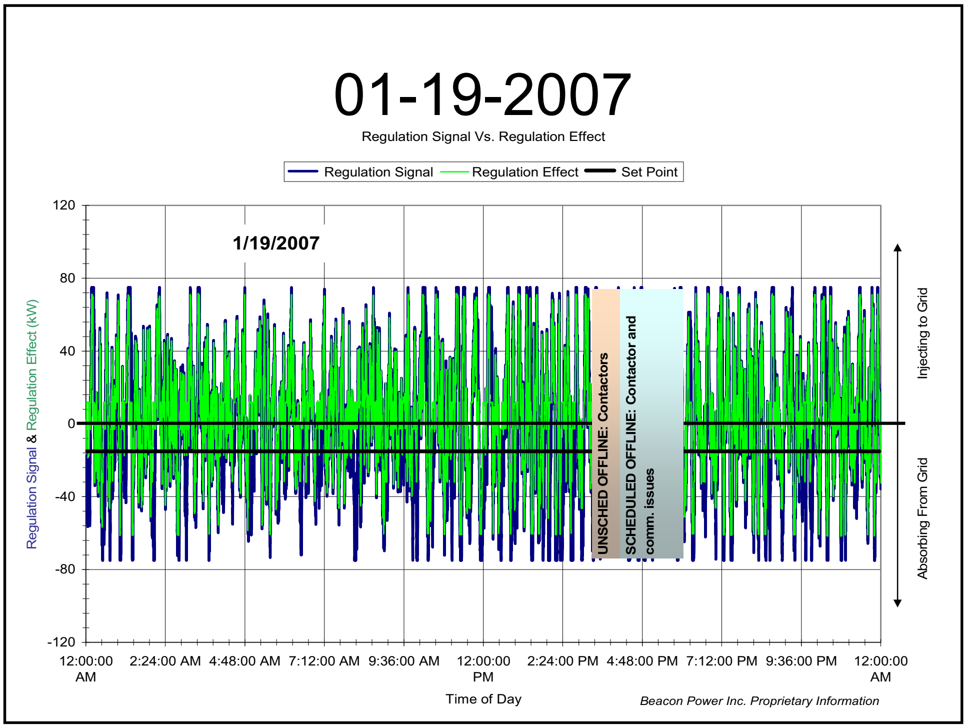

01-16-2007
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
1/16/2007
SCHEDULED OFFLINE: Flatlined regulation signal.
Injecting to Grid
Absorbing From Grid
SETPOINT
Time of Day
Beacon Power Inc. Proprietary Information

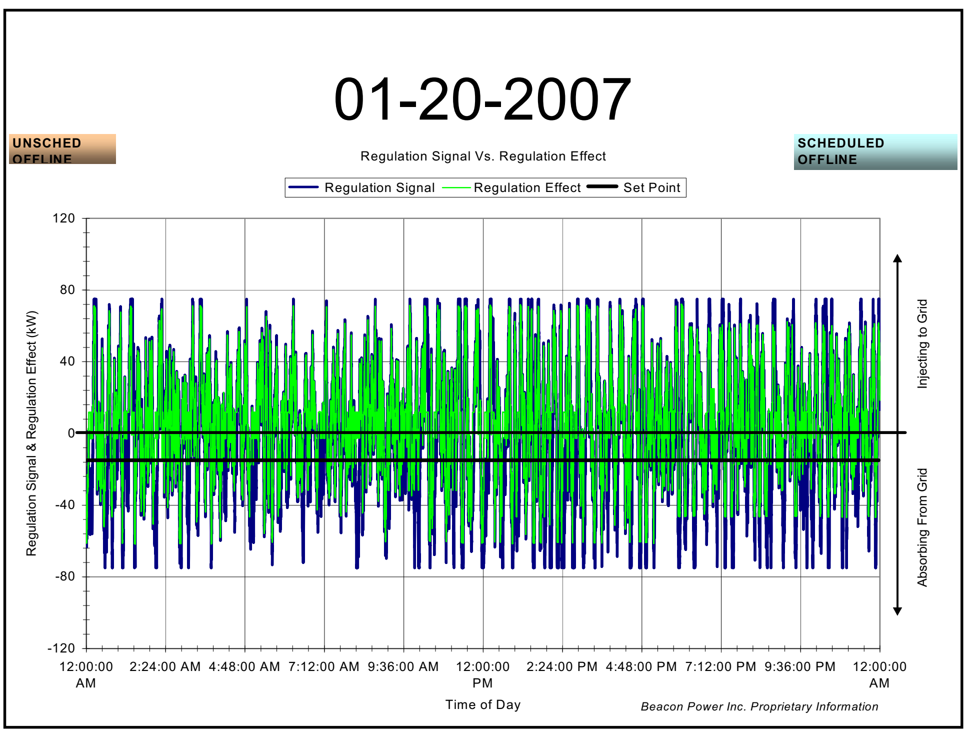
01-17-2007

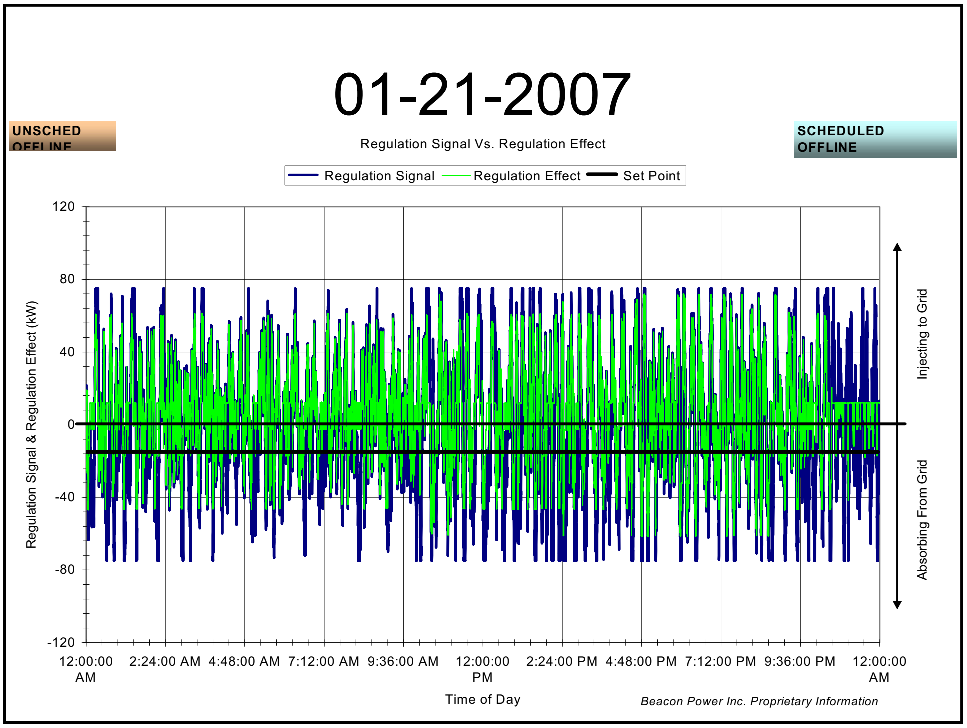


01-18-2007

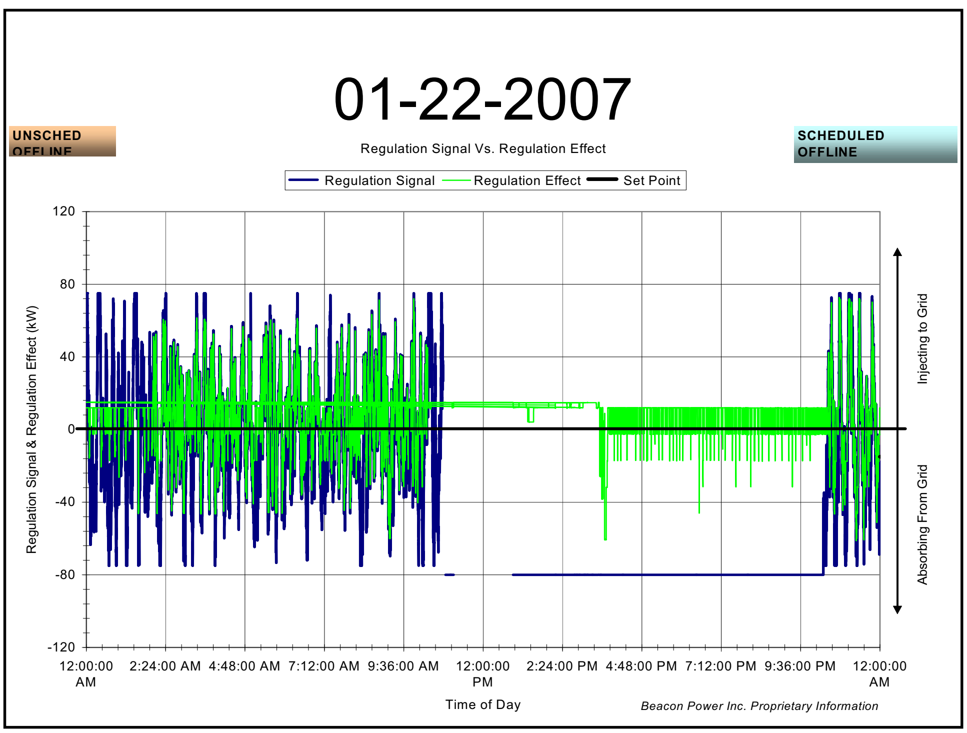



01-19-2007
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
1/19/2007
UNSCHED OFFLINE: Contactors
SCHEDULED OFFLINE: Contactor and comm. issues
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
Time of Day
Beacon Power Inc. Proprietary Information

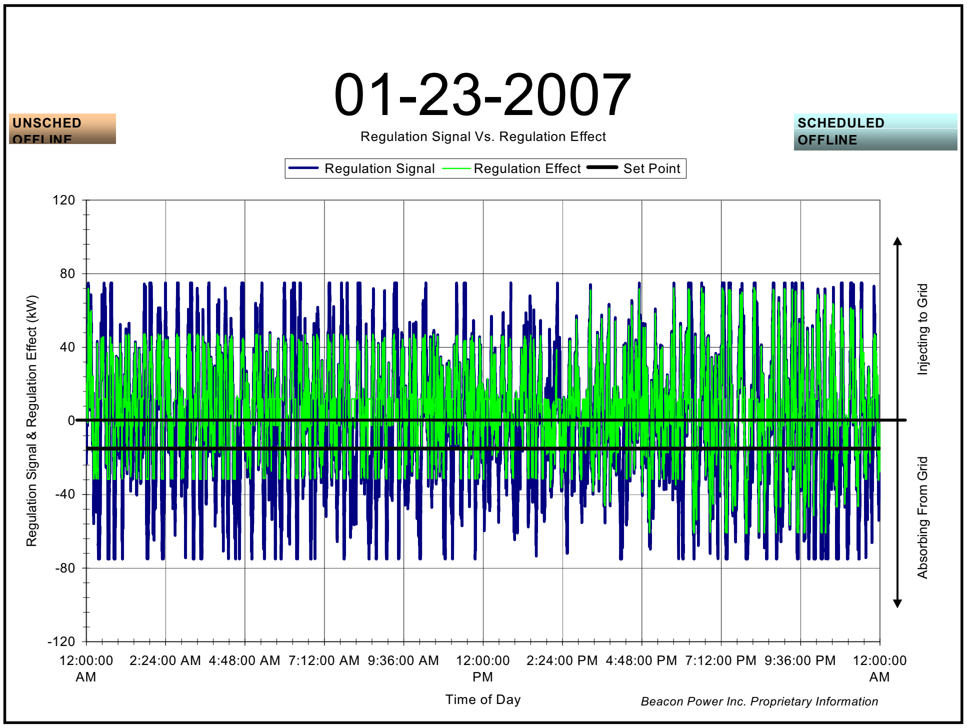

01-20-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
Time of Day
Beacon Power Inc. Proprietary Information

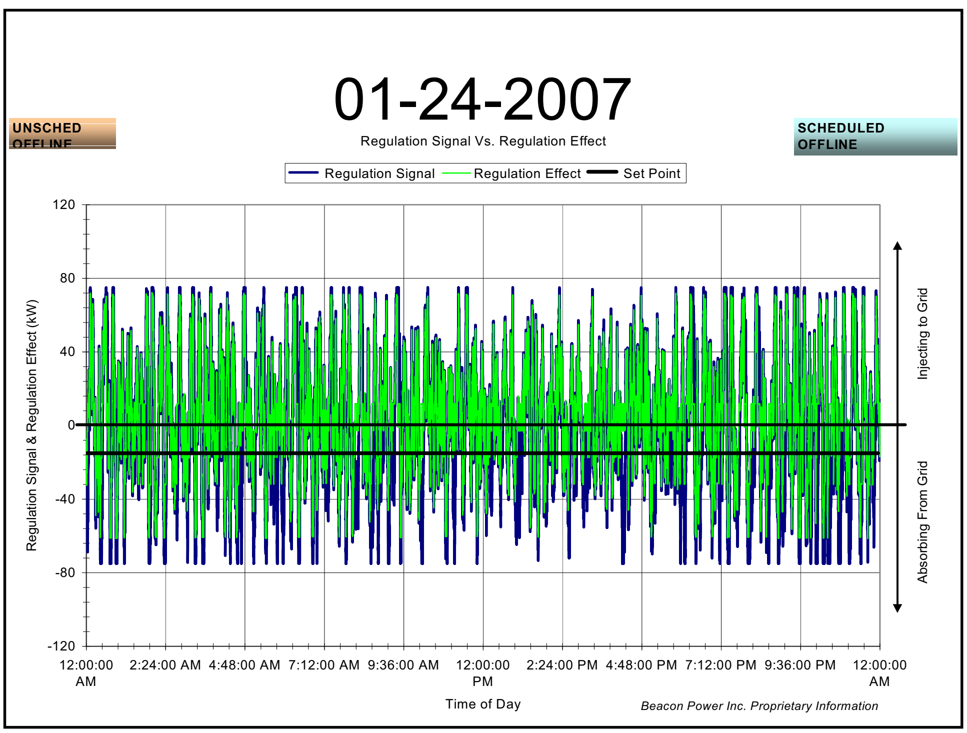


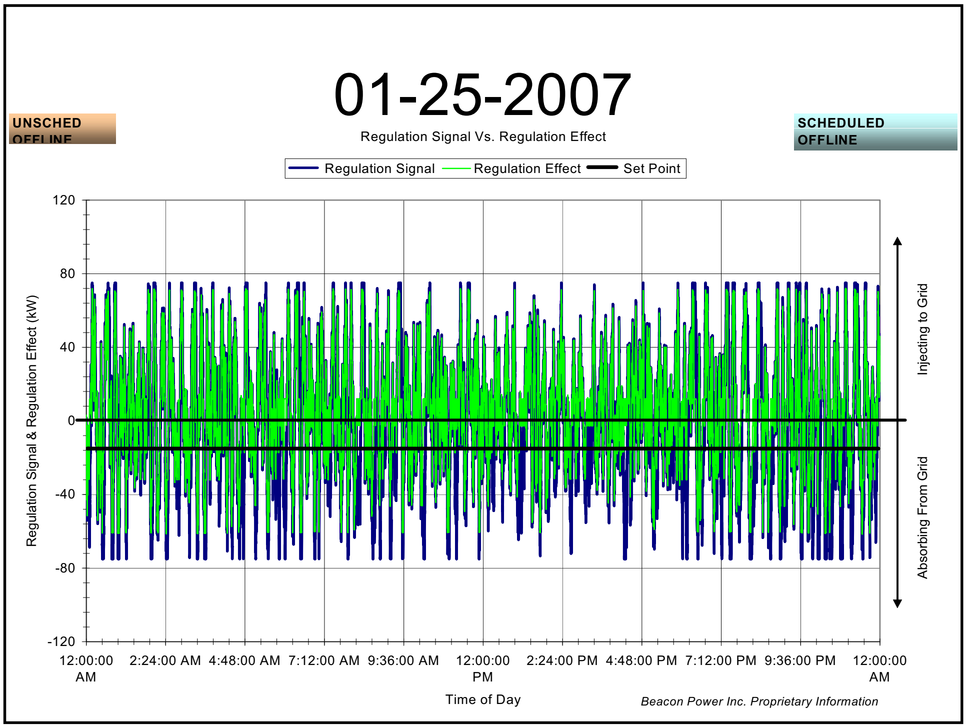
01-21-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information



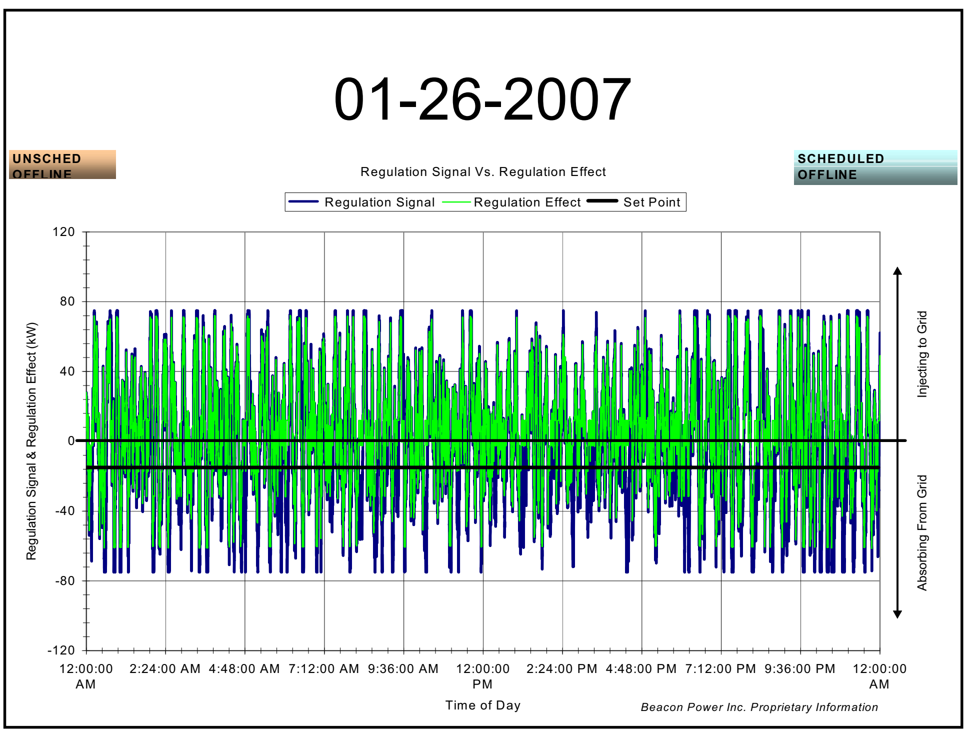
01-22-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information


01-23-2007
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Injecting to Grid
Absorbing From Grid
Beacon Power Inc. Proprietary Information

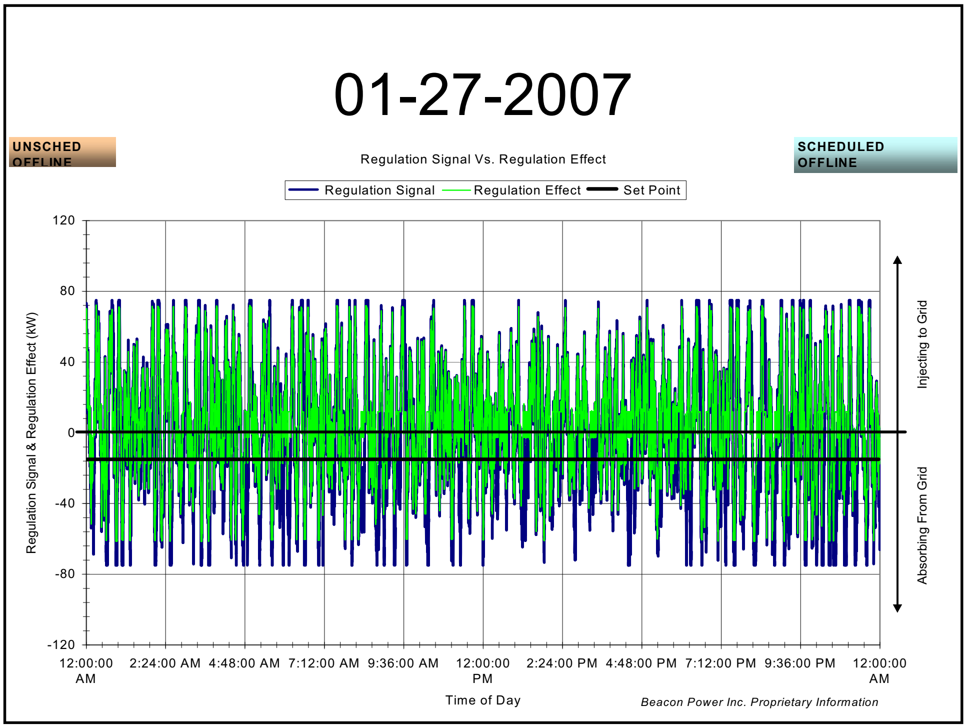

01-24-2007
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Injecting to Grid
Absorbing From Grid
Beacon Power Inc. Proprietary Information

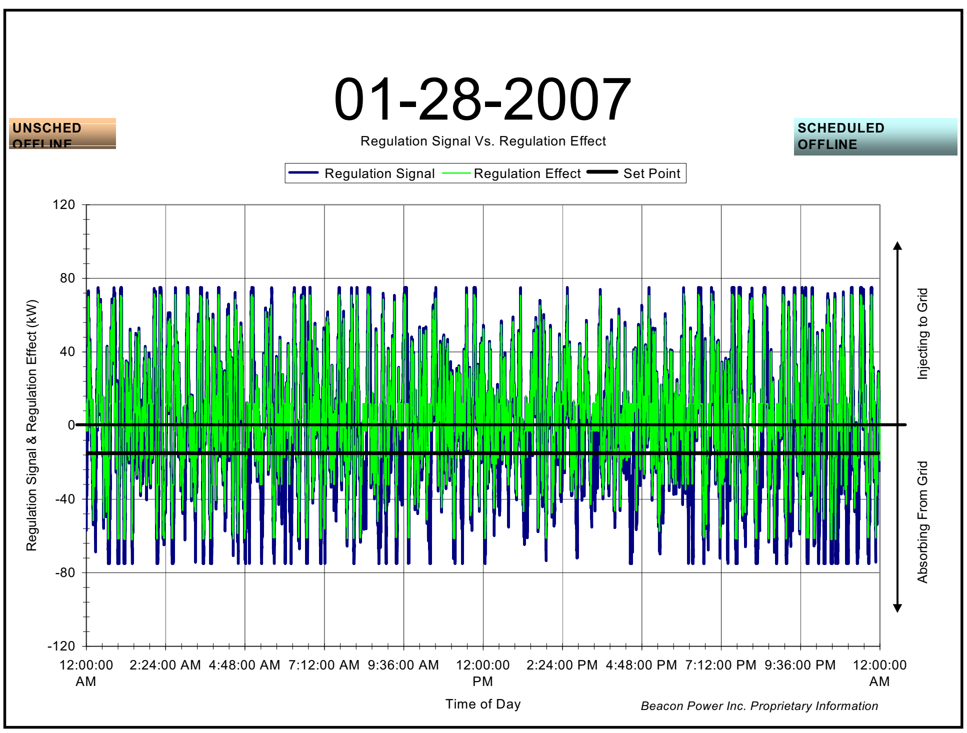


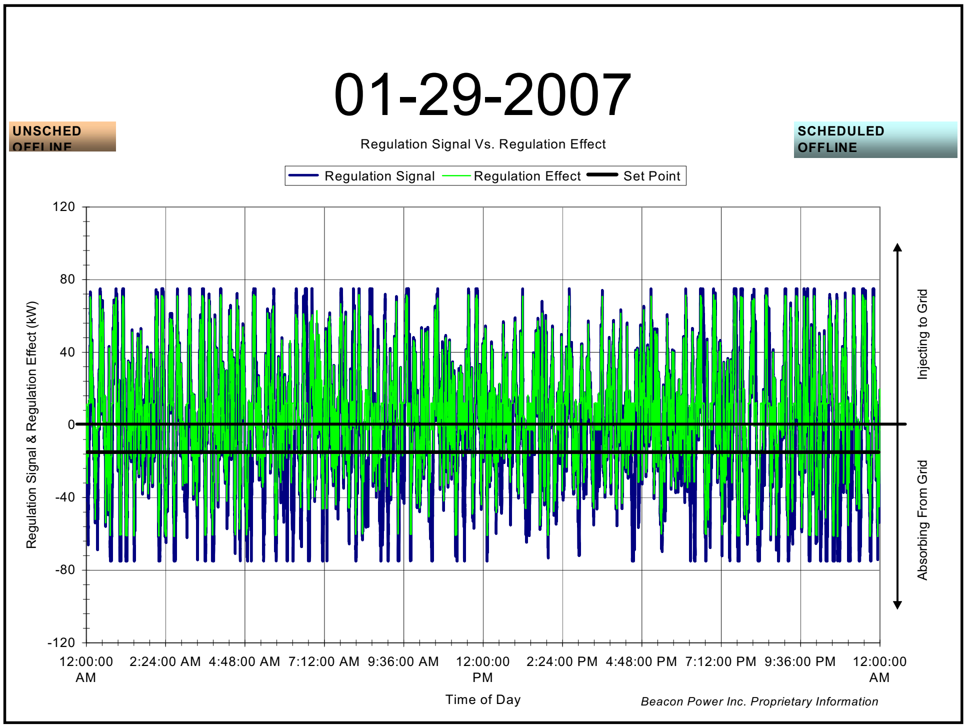
01-25-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

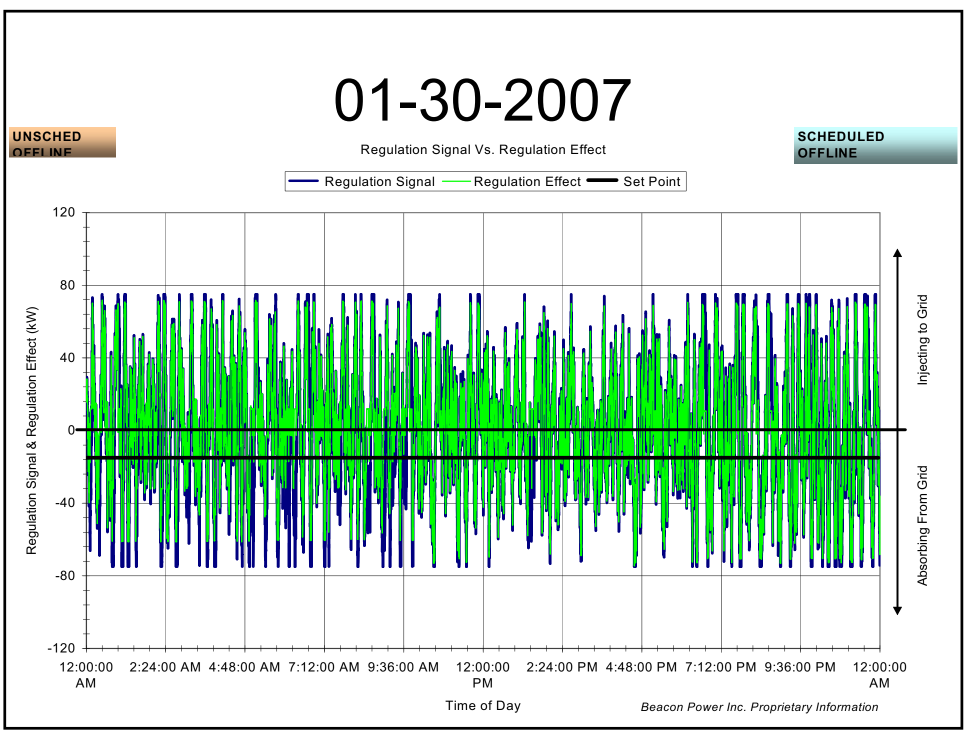


01-26-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

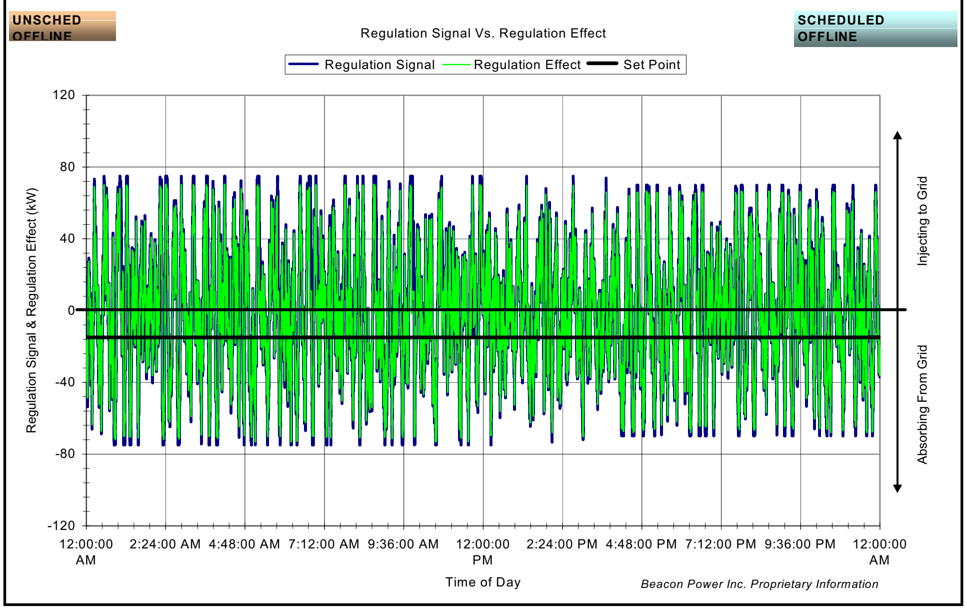

01-27-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information


01-28-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information


01-29-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

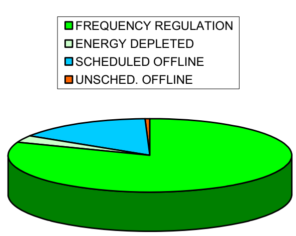

01-30-2007
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

01-31-2007



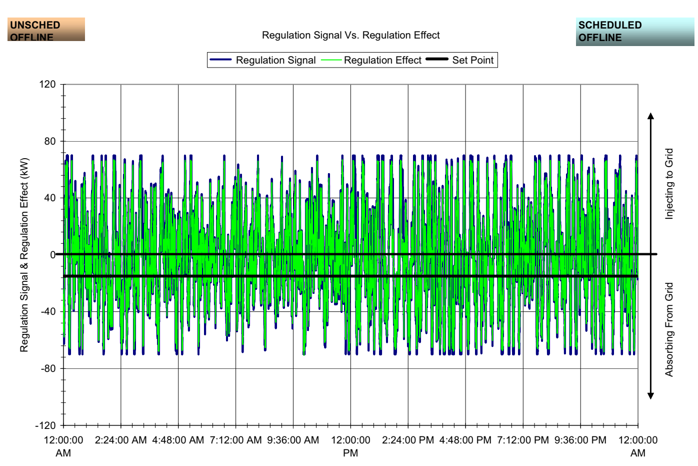
NYSERDA Run Data Monthly Summary Sheet **Date: February, 2007**

		Percent	Hours
DAILY SUMMARY	FREQUENCY REGULATION	81%	14.4
	ENERGY DEPLETED	3%	0.4
	SCHEDULED OFFLINE	15%	9.0
	UNSCHED. OFFLINE	1%	0.2
	Total	100%	24.0
ON-LINE PERFORMANCE	Availability = Freq Reg / 24 Hrs minus Scheduled Offline Hrs	96.8%	
	Deviation Excluding Depleted Time	2.4%	
	Deviation Including Deplete Time	3.4%	

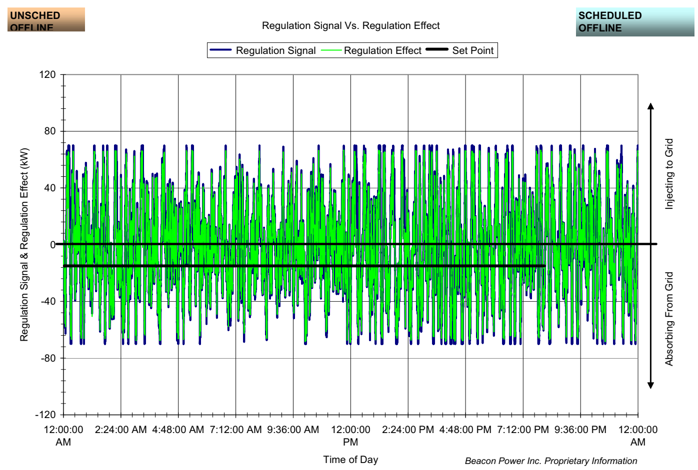


Date	Freq Reg	Energy Depleted	Total Online	offline unsched	offline sched	Avail.	deviation	Deviation w/ depletion	Max KW	Setpoint KW	Cutout Speed RPM	Max FW's
1-Feb	23.38	0.62	24.00	0.00	0.00	97.4%	1.93%	2.91%	70	15	17500	5
2-Feb	23.39	0.61	24.00	0.00	0.00	97.5%	1.91%	2.88%	70	15	17500	5
3-Feb	3.34	0.09	3.43	0.00	20.57	97.4%	7.55%	8.83%	70	15	17500	5
4-Feb	0.00	0.00	0.00	0.00	24.00	96.8%	2.41%	3.37%	63	15	17500	4
5-Feb	12.81	0.19	13.00	1.15	9.84	90.5%	2.66%	3.12%	70	15	17500	5
6-Feb	23.42	0.58	24.00	0.00	0.00	97.6%	1.93%	2.84%	70	15	17500	5
7-Feb	0.00	0.00	0.00	0.00	24.00	96.8%	2.41%	3.37%	63	15	17500	4
8-Feb	0.00	0.00	0.00	0.00	24.00	96.8%	2.41%	3.37%	63	15	17500	4
9-Feb	2.04	0.00	2.04	0.00	21.96	100.1%	3.47%	3.47%	60	15	17500	4
10-Feb	0.00	0.00	0.00	0.00	24.00	96.8%	2.41%	3.37%	63	15	17500	4
11-Feb	0.00	0.00	0.00	0.00	24.00	96.8%	2.41%	3.37%	63	15	17500	4
12-Feb	10.02	0.28	10.30	0.00	13.70	97.3%	2.21%	3.37%	60	15	17500	4
13-Feb	23.07	0.63	23.71	0.30	0.00	96.1%	2.15%	3.18%	60	15	17500	4
14-Feb	10.75	0.37	11.11	0.00	12.89	96.7%	2.20%	3.30%	60	15	17500	4
15-Feb	17.52	0.53	18.05	0.00	5.95	97.1%	2.18%	3.33%	60	15	17500	4
16-Feb	21.08	0.59	21.67	0.25	2.08	96.2%	2.02%	3.04%	60	15	17500	4
17-Feb	12.95	0.48	13.42	0.01	10.57	96.4%	2.26%	3.59%	60	15	17500	4
18-Feb	12.80	0.49	13.29	0.99	9.72	96.8%	2.26%	3.72%	60	15	17500	4
19-Feb	15.94	0.53	16.46	0.26	7.27	95.3%	2.28%	3.52%	60	15	17500	4
20-Feb	11.94	0.43	12.37	1.69	9.95	96.8%	2.47%	3.78%	60	15	17500	4
21-Feb	16.67	0.52	17.19	0.00	6.81	97.0%	1.69%	2.41%	90	15	17500	4
22-Feb	23.34	0.66	23.99	0.01	0.00	96.8%	0.93%	1.18%	60	15	17500	4
23-Feb	23.36	0.64	23.99	0.01	0.00	97.3%	2.41%	3.43%	60	15	17500	4
24-Feb	23.36	0.64	24.00	0.00	0.00	97.3%	2.47%	3.48%	60	15	17500	4
25-Feb	23.34	0.65	23.98	0.02	0.00	97.2%	2.48%	3.51%	60	15	17500	4
26-Feb	23.34	0.65	23.99	0.01	0.00	97.3%	2.47%	3.48%	60	15	17500	4
27-Feb	23.36	0.64	24.00	0.00	0.00	97.3%	2.44%	3.46%	60	15	17500	4
28-Feb	23.35	0.65	24.00	0.00	0.00	96.8%	0.90%	1.17%	60	15	17500	4
Total	14.4	0.4	14.9	0.2	9.0	96.8%	2.4%	3.4%				

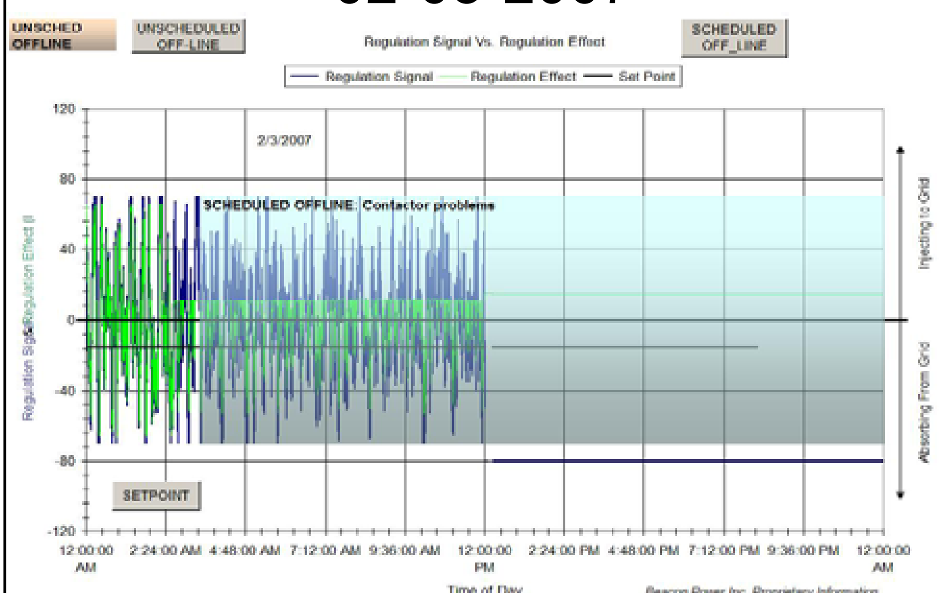
02-01-2007

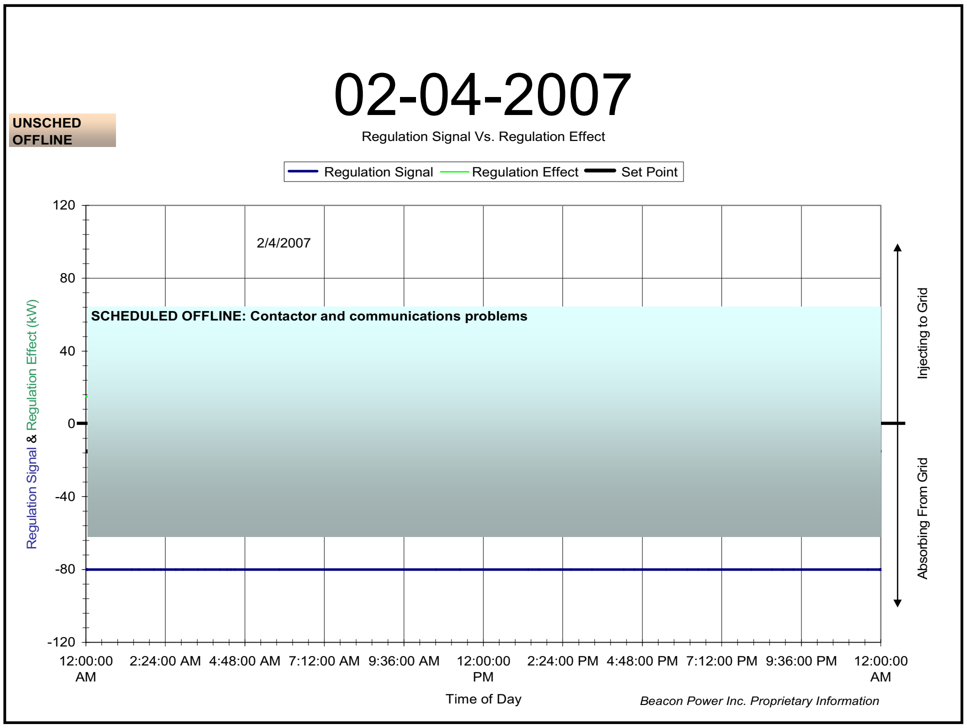


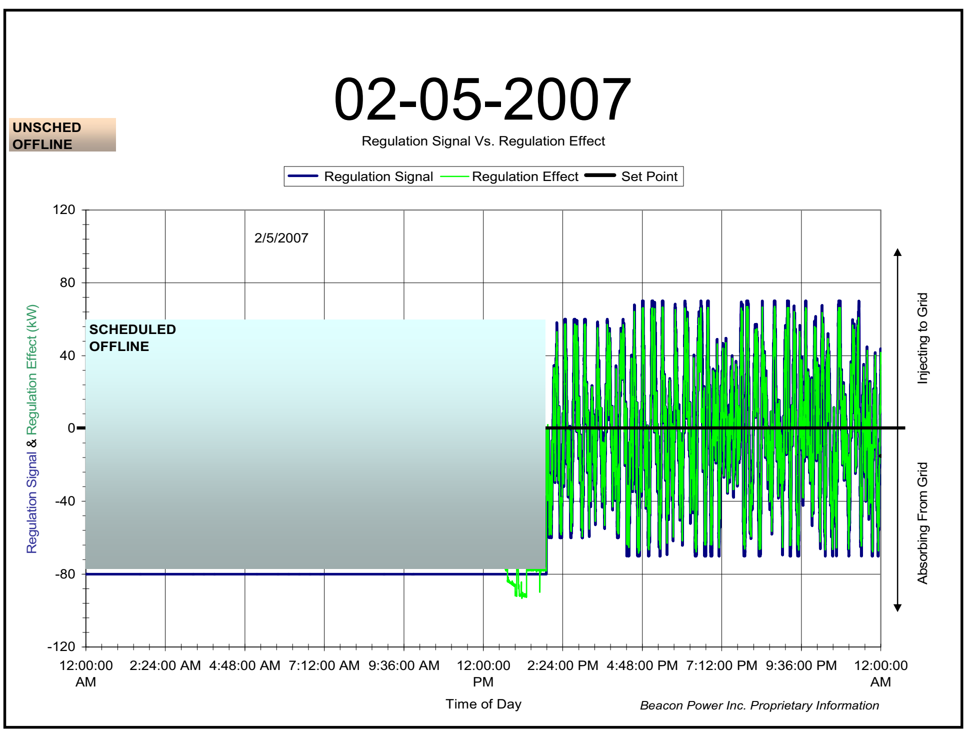
02-02-2007

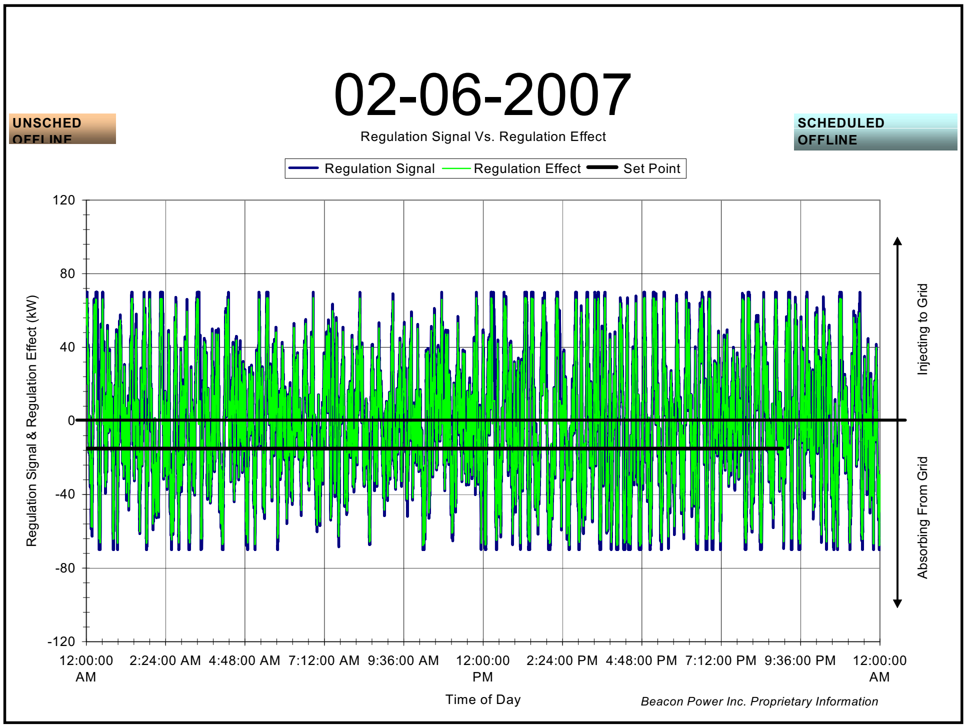


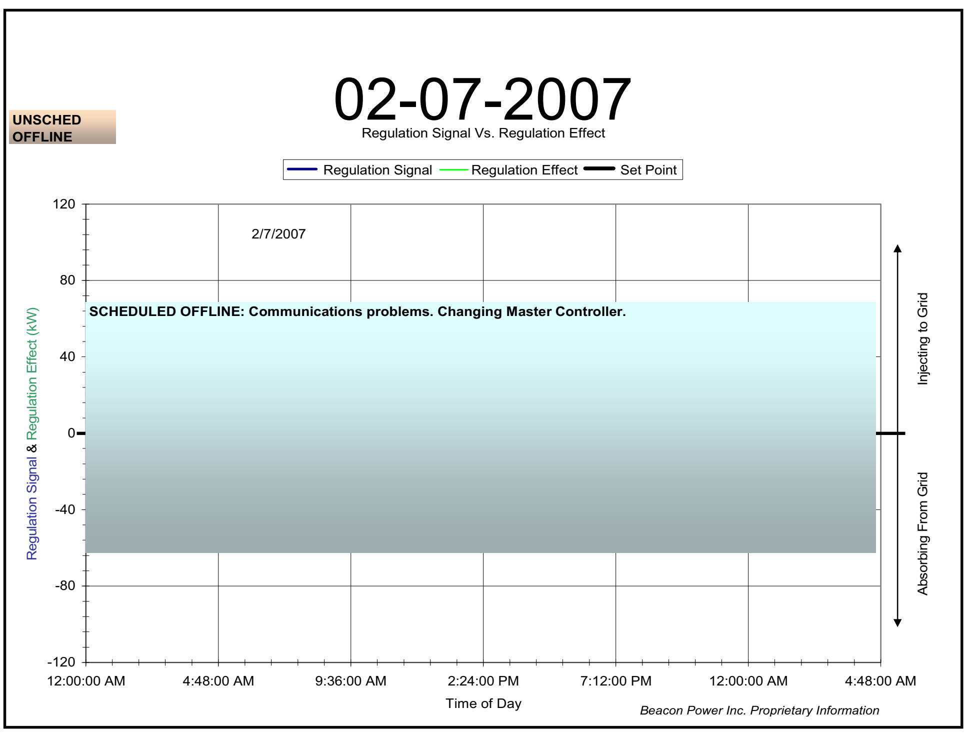
02-03-2007

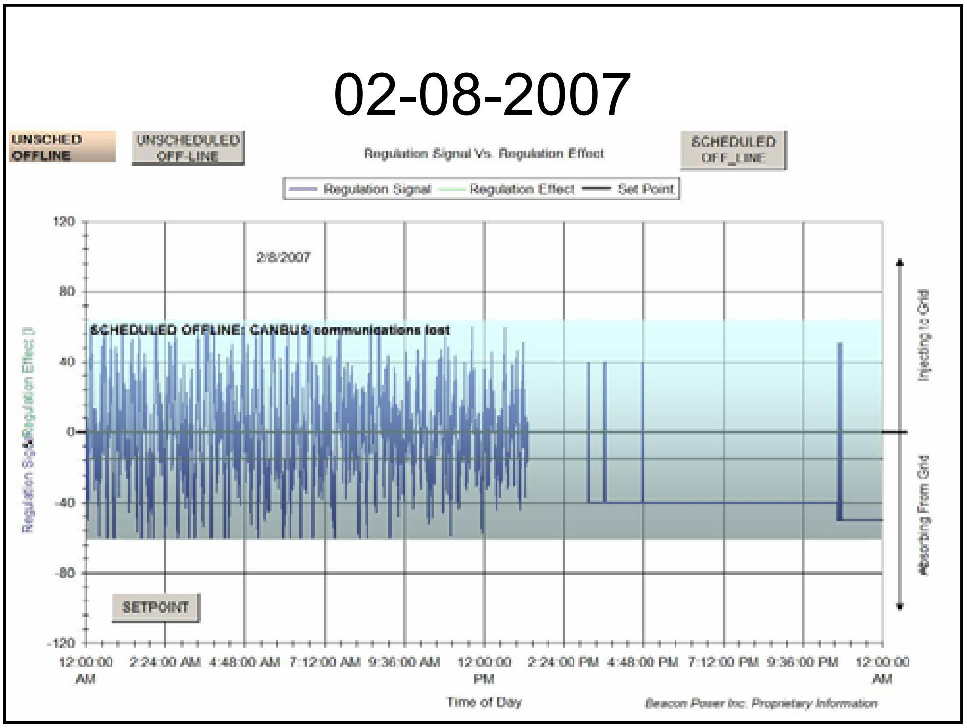


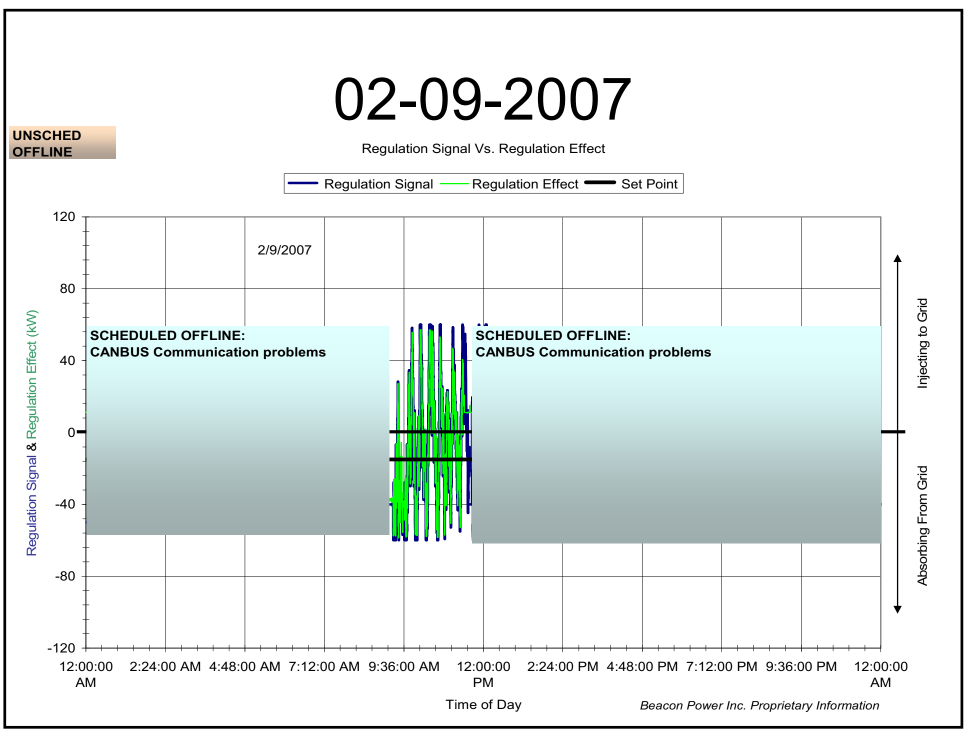

02-04-2007
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
Regulation Signal
Regulation Effect
Set Point
2/4/2007
SCHEDULED OFFLINE: Contactor and communications problems
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Injecting to Grid
Absorbing From Grid
Beacon Power Inc. Proprietary Information

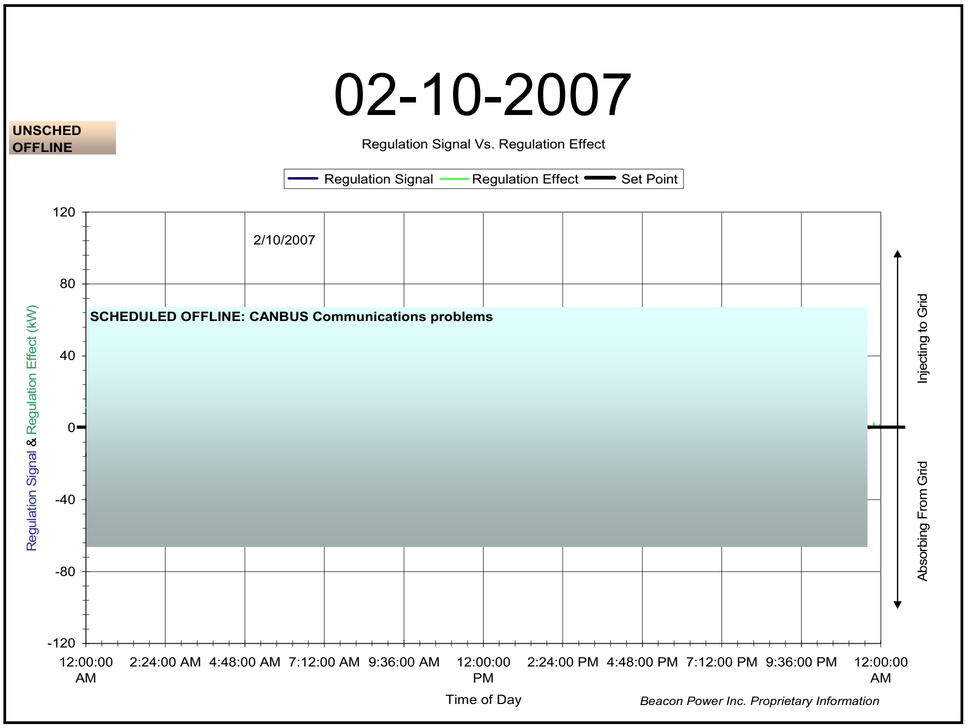

02-05-2007
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
Regulation Signal
Regulation Effect
Set Point
2/5/2007
SCHEDULED OFFLINE
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Injecting to Grid
Absorbing From Grid
Beacon Power Inc. Proprietary Information

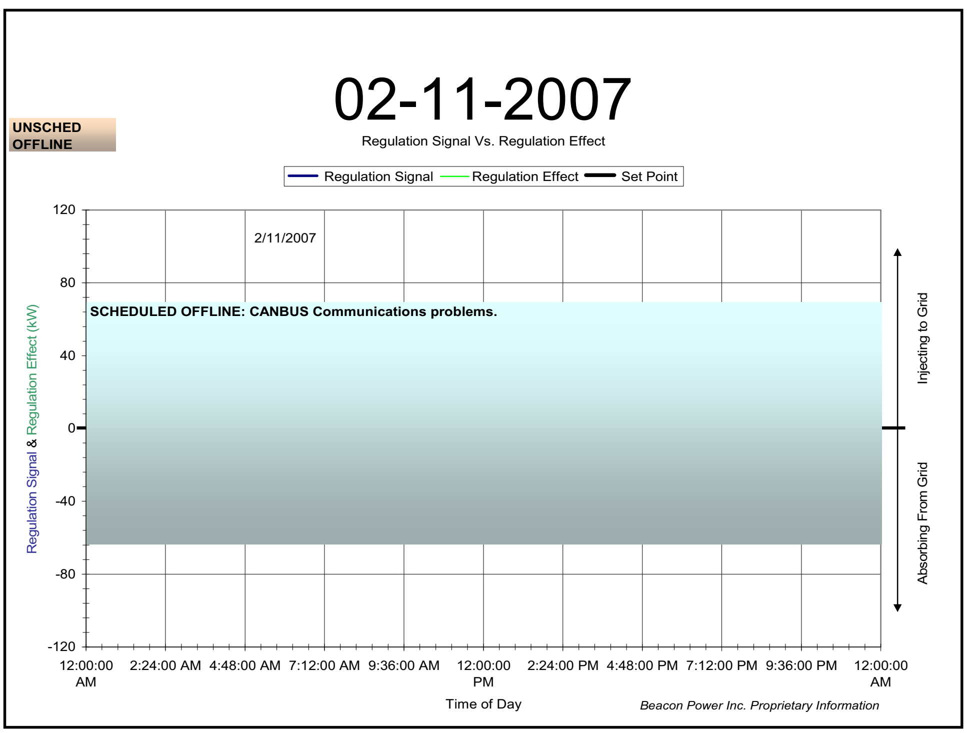

02-06-2007
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

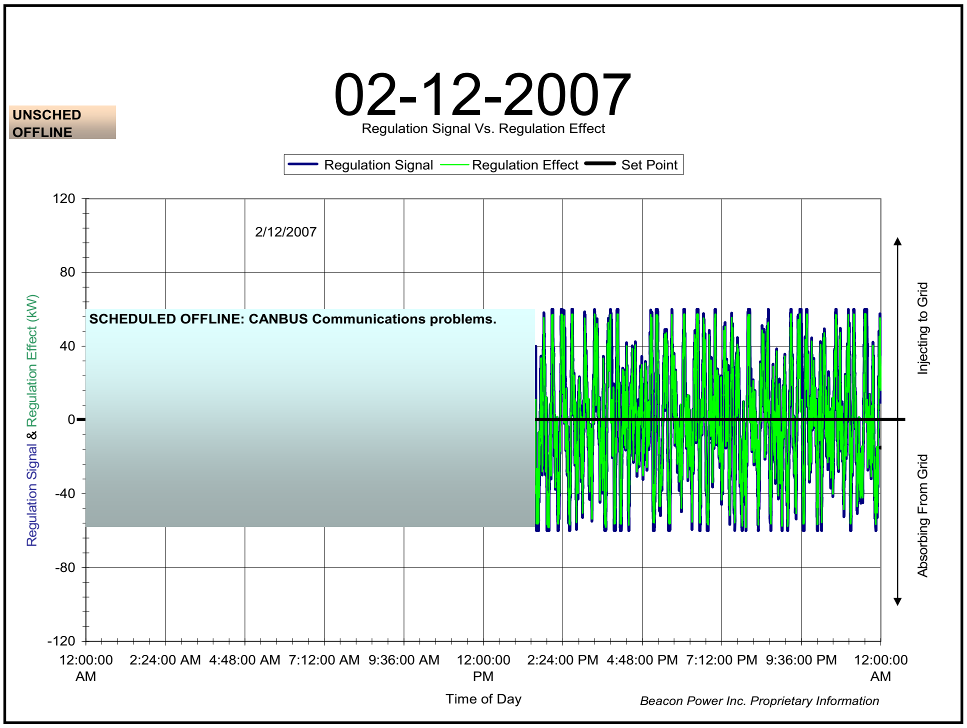

02-07-2007
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
Regulation Signal
Regulation Effect
Set Point
2/7/2007
SCHEDULED OFFLINE: Communications problems. Changing Master Controller.
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
4:48:00 AM
9:36:00 AM
2:24:00 PM
7:12:00 PM
12:00:00 AM
4:48:00 AM
Time of Day
Beacon Power Inc. Proprietary Information


02-08-2007
UNSCHED OFFLINE
UNSCHEDULED OFF-LINE
Regulation Signal Vs. Regulation Effect
SCHEDULED OFF_LINE
Regulation Signal
Regulation Effect
Set Point
2/8/2007
SCHEDULED OFFLINE: CANBUS communications lost
SETPOINT
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

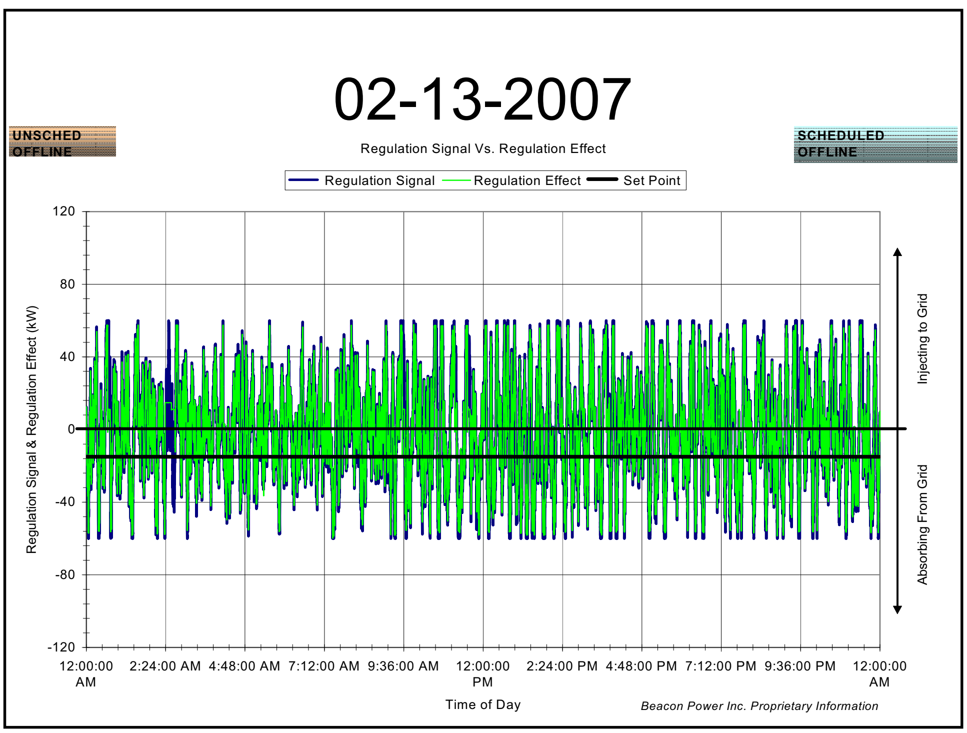

02-09-2007
UNSCHED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
2/9/2007
Regulation Signal & Regulation Effect (kW)
SCHEDULED OFFLINE:
CANBUS Communication problems
SCHEDULED OFFLINE:
CANBUS Communication problems
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information


02-10-2007
UNSCHED
OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
2/10/2007
SCHEDULED OFFLINE: CANBUS Communications problems
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

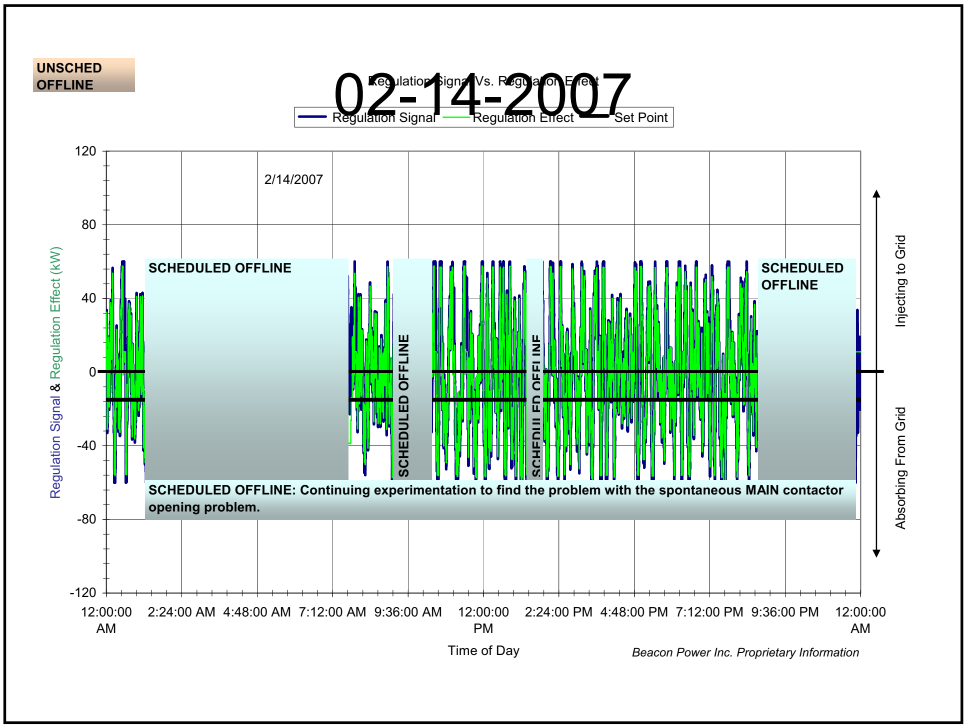

02-11-2007
UNSCHED
OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
2/11/2007
SCHEDULED OFFLINE: CANBUS Communications problems.
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

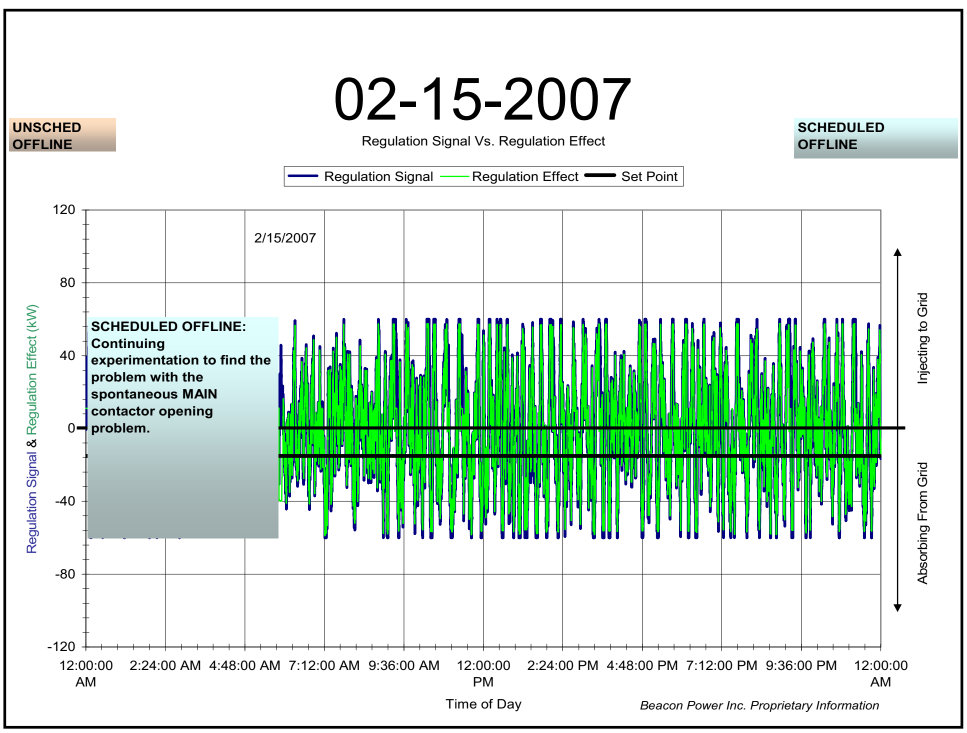


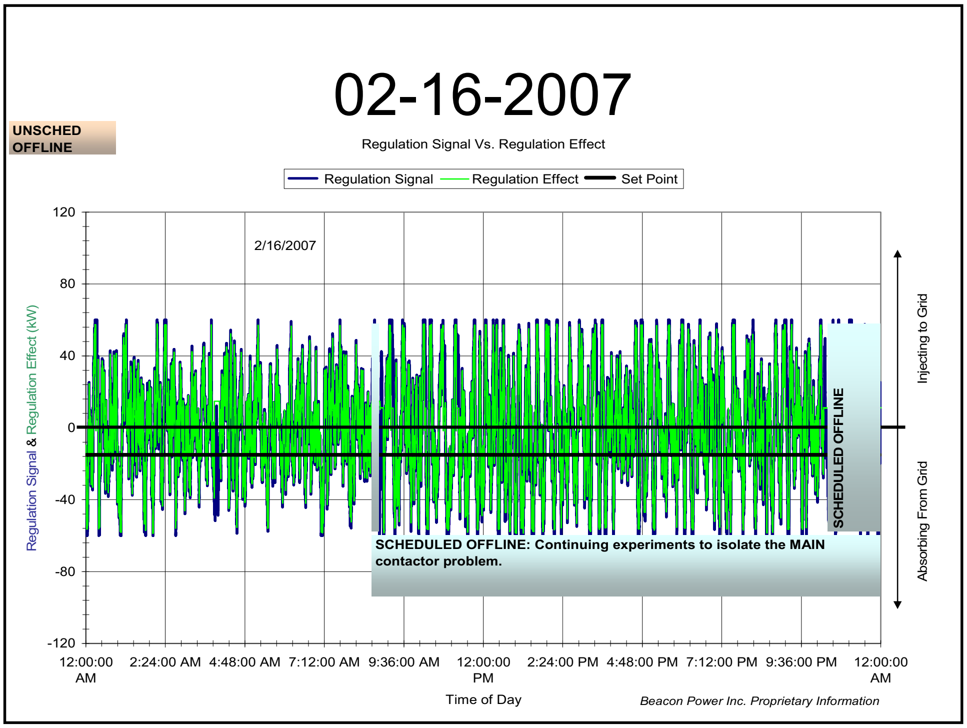
UNSCHED
OFFLINE
02-12-2007
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
2/12/2007
SCHEDULED OFFLINE: CANBUS Communications problems.
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

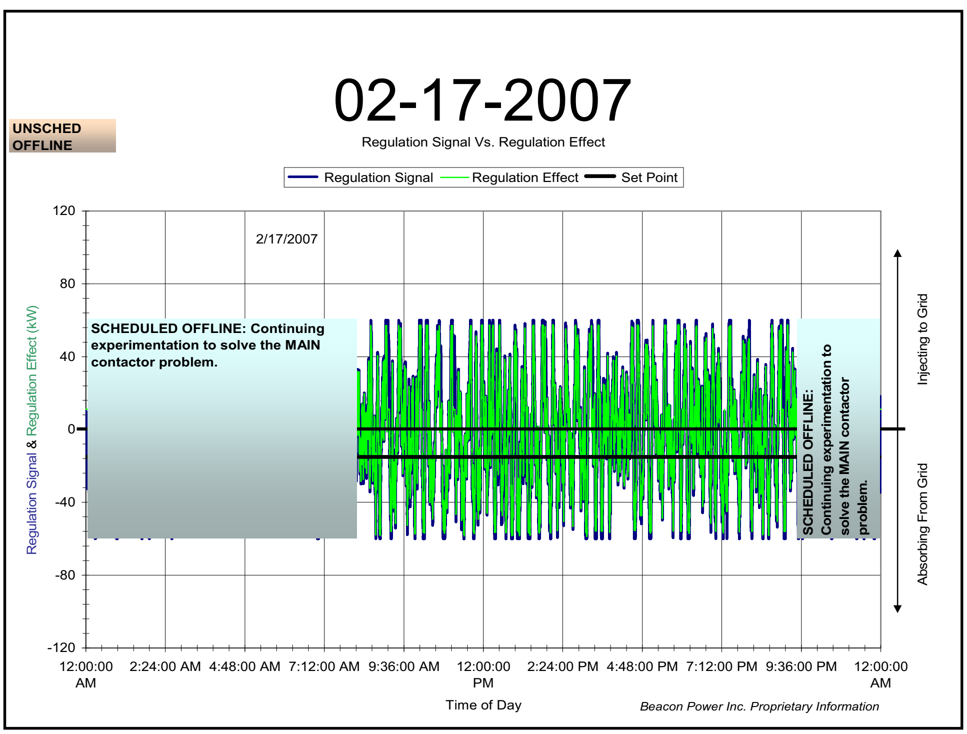


02-13-2007
UNSCHED
OFFLINE
SCHEDULED
OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
120
80
40
0
-40
-80
-120
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information


UNSCHED OFFLINE
02-14-2007
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
2/14/2007
SCHEDULED OFFLINE
SCHEDULED OFFLINE
SCHEDULED OFFLINE
SCHEDULED OFFLINE: Continuing experimentation to find the problem with the spontaneous MAIN contactor opening problem.
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
Time of Day
Beacon Power Inc. Proprietary Information

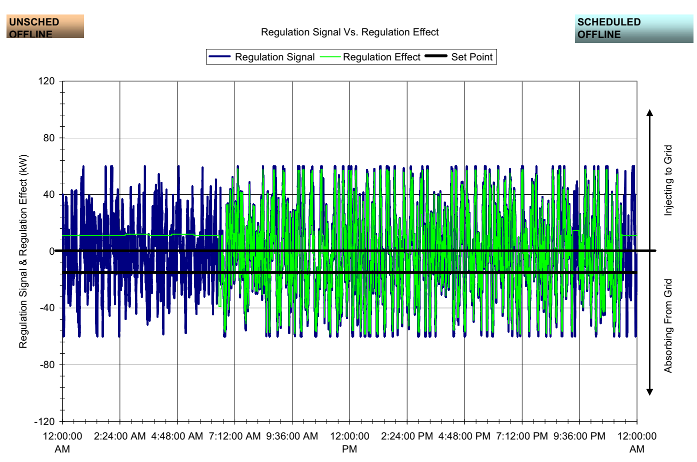

02-15-2007
Regulation Signal Vs. Regulation Effect
UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal
Regulation Effect
Set Point
2/15/2007
SCHEDULED OFFLINE: Continuing experimentation to find the problem with the spontaneous MAIN contactor opening problem.
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
Time of Day
Beacon Power Inc. Proprietary Information


02-16-2007
UNSCHED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
2/16/2007
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
SCHEDULED OFFLINE
SCHEDULED OFFLINE: Continuing experiments to isolate the MAIN contactor problem.
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information


02-17-2007
UNSCHED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
2/17/2007
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
SCHEDULED OFFLINE: Continuing experimentation to solve the MAIN contactor problem.
SCHEDULED OFFLINE: Continuing experimentation to solve the MAIN contactor problem.
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

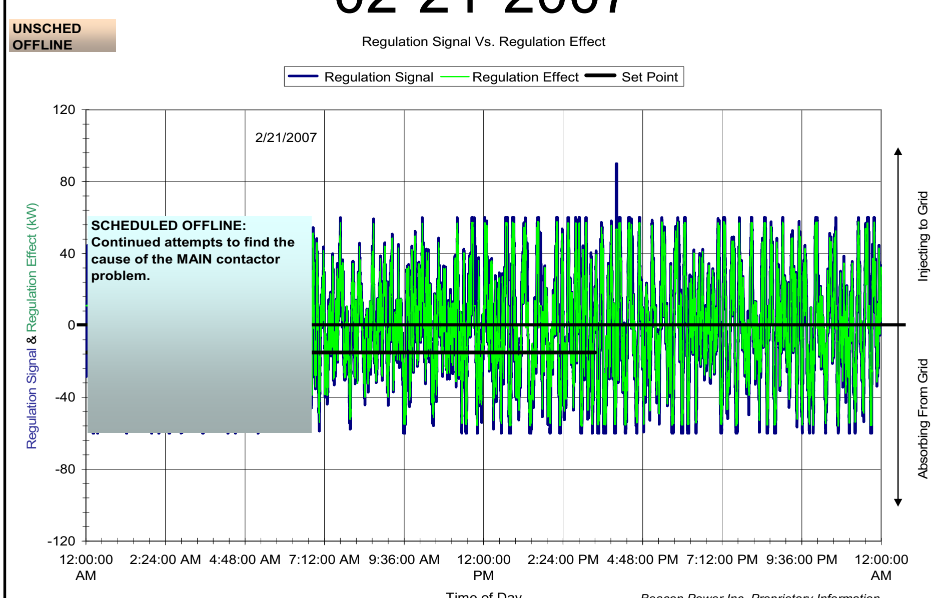
02-18-2007

02-19-2007



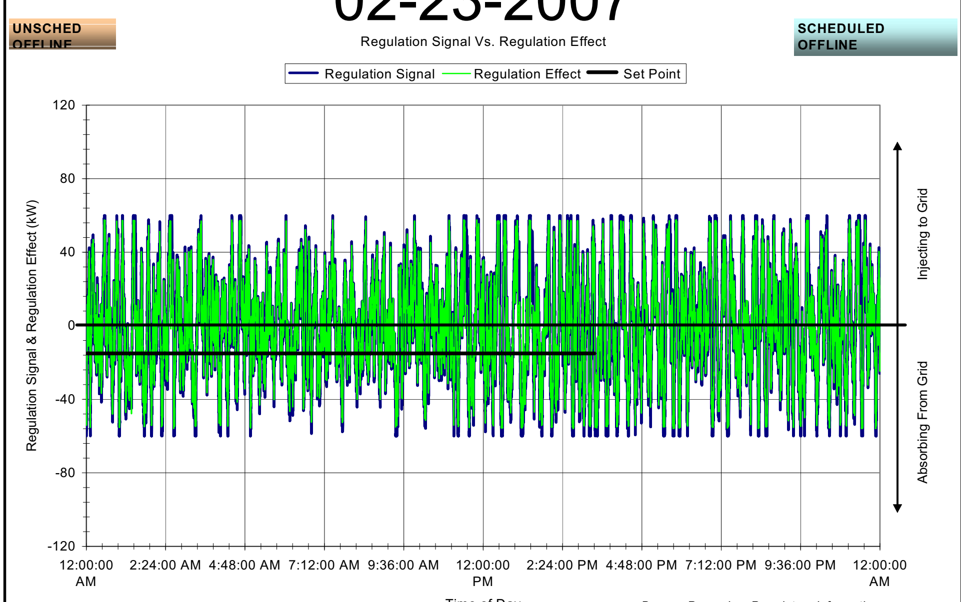
02-20-2007

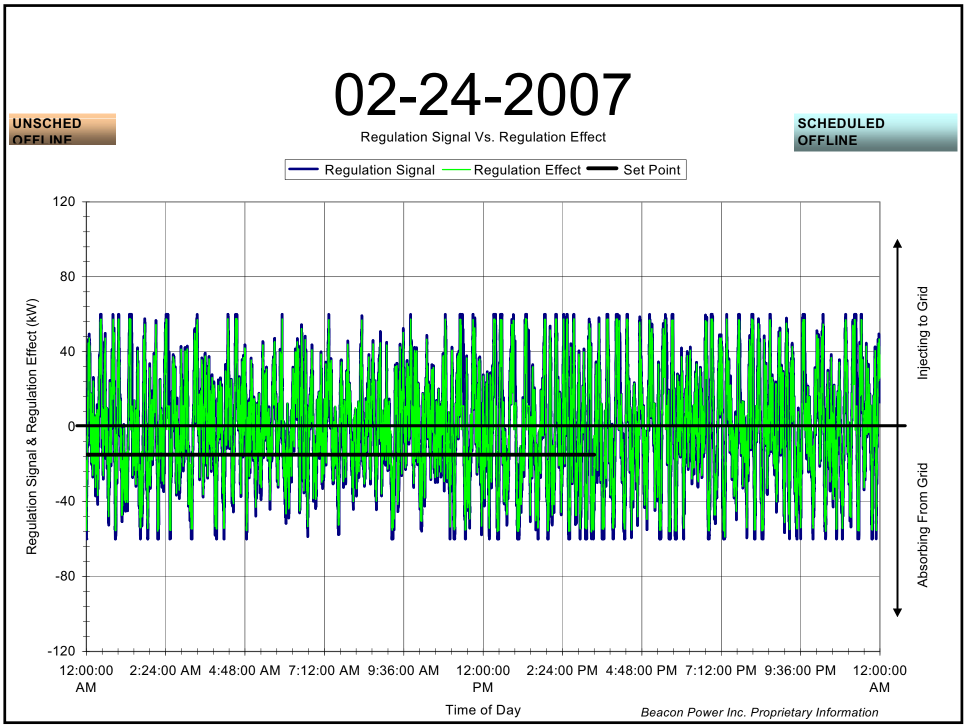
02-21-2007



02-22-2007

02-23-2007

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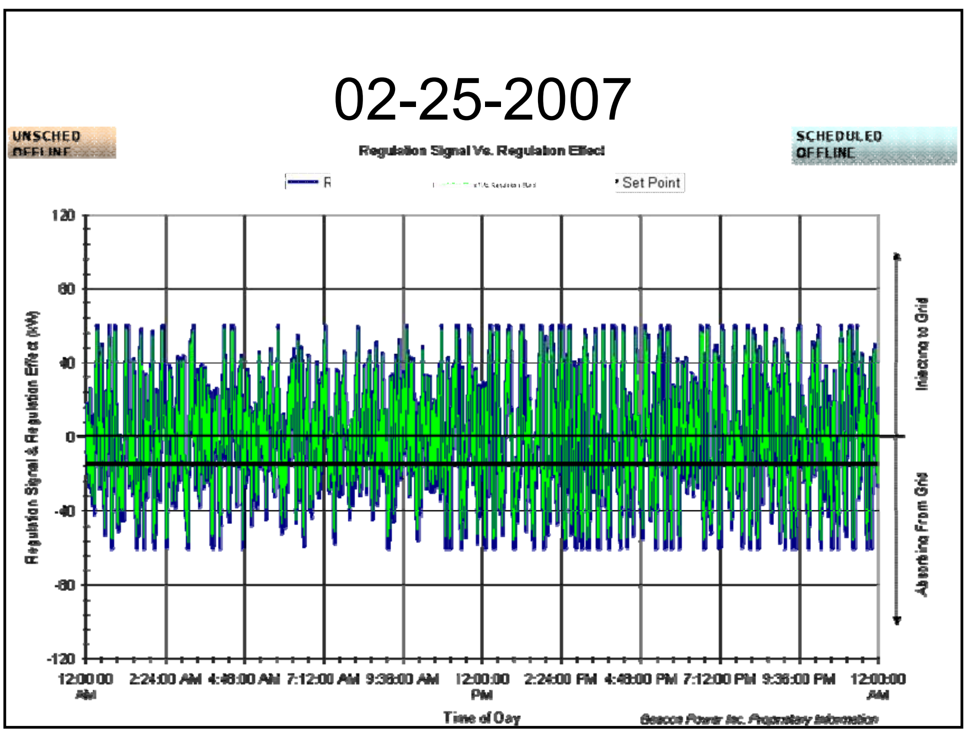
SCHEDULED OFFLINE
Regulation Signal Vs. Regulation Effect
Regulation Signal
Regulation Effect
Set Point
Regulation Signal & Regulation Effect (kW)
120
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information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Set Point
Regulation Signal & Regulation Effect (kW)
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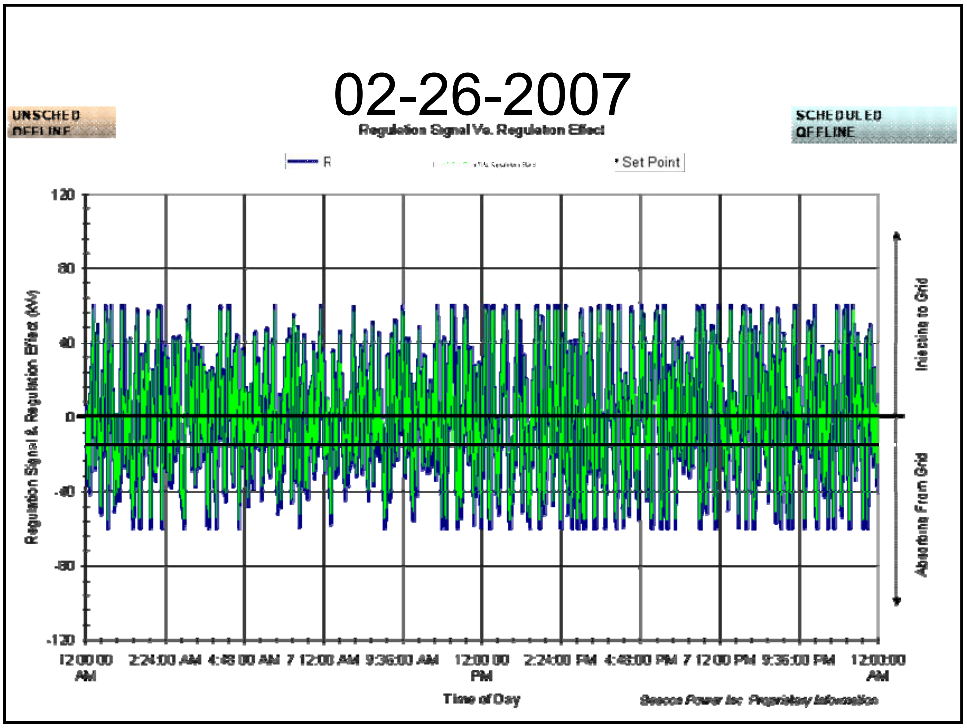
80
40
0
-40
-80
-120
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information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Set Point
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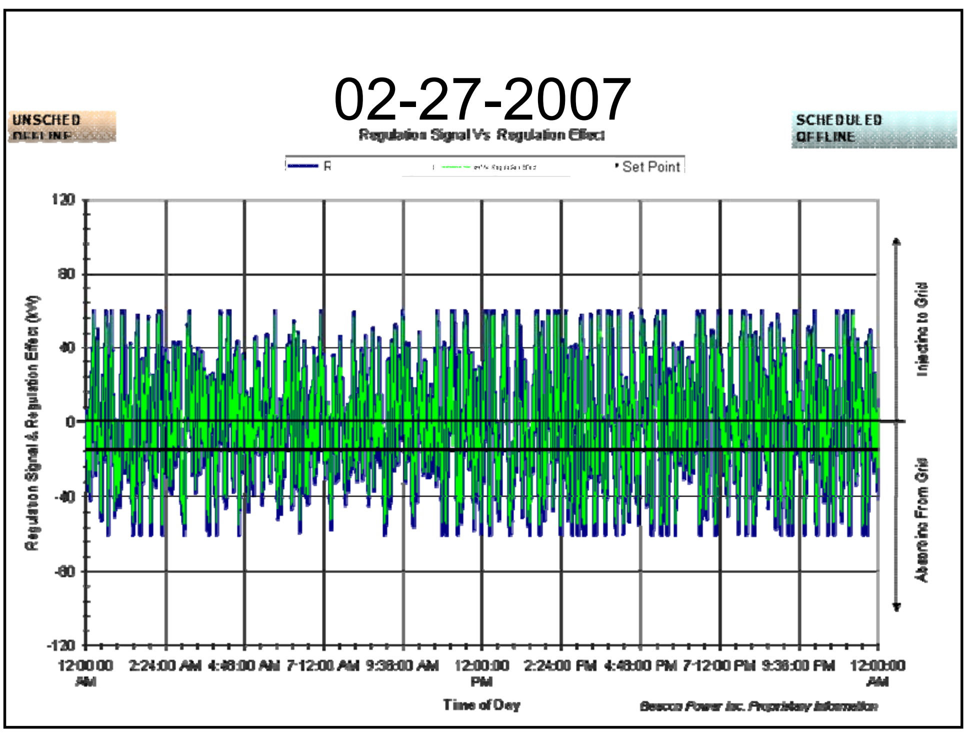
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information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UNSCHED OFFLINE
SCHEDULED OFFLINE
Regulation Signal Vs Regulation Effect
Set Point
120
80
40
0
-40
-80
-120
Regulation Signal & Regulation Effect (kW)
Injecting to Grid
Absorbing From Grid
12:00:00 AM
2:24:00 AM
4:48:00 AM
7:12:00 AM
9:36:00 AM
12:00:00 PM
2:24:00 PM
4:48:00 PM
7:12:00 PM
9:36:00 PM
12:00:00 AM
Time of Day
Beacon Power Inc. Proprietary Information

Appendix 8.9
DOE Independent Evaluation of Data

Status Update On The NYSERDA/DOE Joint Energy Storage Initiative Projects[1]

Jeff Lamoree (EnerNex Corporation, Knoxville, Tennessee, USA) jeff@enernex.com; Georgianne Peek (Sandia National Laboratories);[2] Joseph Sayer (NYSERDA); Mark Schneider (Delaware County Electric Cooperative); Jim Arseneaux (Beacon Power); Ib Olsen (Gaia Power Technologies)

Acknowledgements

- The Data Acquisition and Analysis for these demonstration projects is funded by the U.S. Department of Energy. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
  - Project Manager - Georgianne Peek, Sandia National Lab

In 2004, the U.S. Department of Energy (DOE) and the New York State Energy Research and Development Authority (NYSERDA) commissioned three energy storage research projects. A fourth project was added in 2007. The four projects are as follows:

- Gaia Power Technologies/Delaware County Electric Cooperative – Edge of grid residential application that includes an 11 kW PowerTower battery-based energy storage and delivery system fed by a Plug Power 5 kW fuel cell in Delhi, NY as well as the grid
- Beacon Power – Grid frequency regulation demonstration at an industrial facility in Amsterdam, NY, using 7 flywheels producing 100 kW for 15 minutes
- New York Power Authority/ABB – Peak-shaving and emergency backup application utilizing a 1 MW/7.2 MWh commercial-scale sodium-sulfur (NAS) battery system at a Long Island Bus facility
- Gaia Power Technologies/Princeton Power – Peak-shaving demonstration at industrial customer in DCEC territory with four 75 kW/225 kWh Power Tower units

This paper will present the status of each of the above mentioned energy storage projects and any results gathered up to the time of the paper submission deadline. The core requirements for the data acquisition system came out of the original PON 846 and are as follows:

- The proposed EES must include a Data Acquisition System (DAS) for the purpose of providing system operating data to be used for evaluation and generation of reports on the overall performance of the EES.
- Data acquisition rates must be adequate to monitor the application that the system is designed to perform. For example, power quality operations require high-speed data acquisition, on the order of micro-seconds, to adequately capture power quality or system stability events.
- In contrast, energy management operations such as peak shaving or arbitrage applications, require sampling on the order of milli-seconds to seconds with 15 minute averages.
- In the event that the demonstration system performs multiple activities, the DAS must provide for the collection of data for all activities.

The approach that we are utilizing for the design of the DAS system is as follows:

- Convert data from vendor systems into standard formats
  - IEEE 1159.3 PQDIF
  - IEC 61850 data models for metering
- Transport to EnerNex monitoring center via secure communications link over Internet
- Expose via dynamically generated tables, graphs on demand on project web site
- Provide project information, archived data and real-time data on open project web site
  - www.storagemonitoring.com

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[1] This project is part of the Joint Energy Storage Initiative between the New York State Energy Research and Development Authority (NYSERDA) and the Energy Storage Systems Program of the U.S. Department of Energy (DOE/ESS), and managed by Sandia National Laboratories (SNL).

[2] Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Site 1 - Gaia Power Technologies/Delaware County Electric Cooperative, Inc.

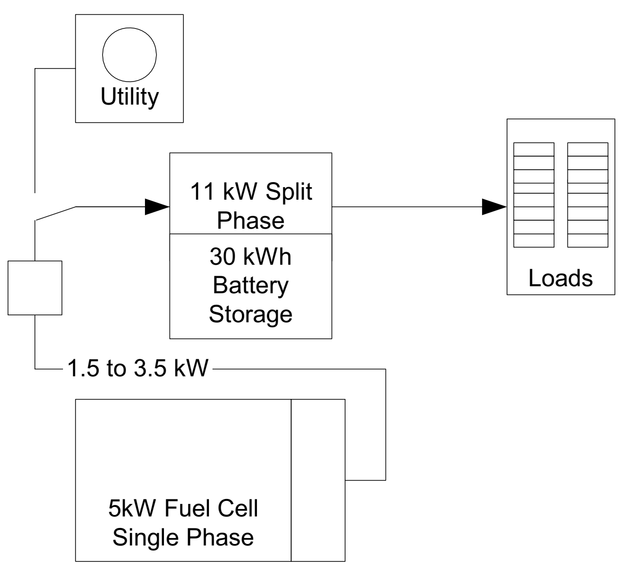
The first project mentioned above, the application of a Gaia PowerTower, is complete. Construction and installation was completed in June, 2005 and monitoring continued through March, 2007. The total load, as well as both inputs to the PowerTower, were monitored both for energy and power quality. In addition, several other data inputs were collected including BTU flow meter, temperature, humidity, and propane fuel consumption. The system did illustrate that a residence on the edge of the grid could in fact power his/her home with a combination battery energy storage device and fuel cell. Several power quality issues surfaced, most notably voltage flicker problems, which will be highlighted in the paper.

Timeline

- Gaia Power Tower and Plug Power Fuel Cell installed in June, 2005
- System operational in July 2005
- Fuel cell shut down in June, 2006, removed July, 2006
- System restarted in September, 2006 with grid supplying Power Tower
- Briggs 15 kW generator installed in March, 2007
- Monitoring continued until April, 2007

Operation

- Fuel cell supplied about 2kW to the Power Tower on a continuous basis
- Power Tower continuously supplied house load unless either leg went above 5.5kW or 45 amps
- If load went above, load shedding relaying operated, followed by full load transfer back to grid



Project Summary

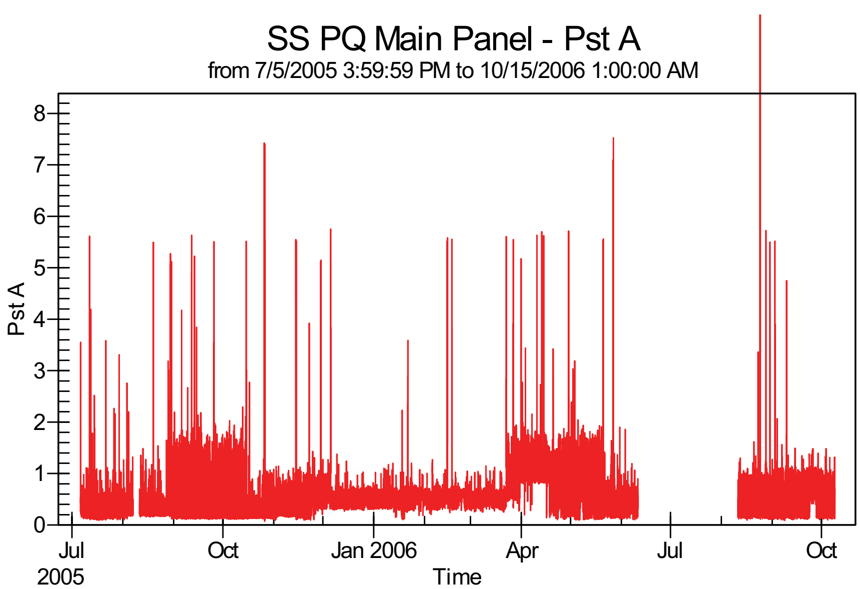
Month	System Mode
July, 2005	Fuel Cell ON (But new stack was installed during the last week of month)
August	Fuel Cell ON (Net metering but back to full mode on Aug 30th)
September	Fuel Cell ON
October	Fuel Cell ON (Until Oct 26th when outage occurred)
November	Fuel Cell ON (Primarily netmetering then set to OFF position followed by brief operation on Nov 22nd)
December	Fuel Cell OFF
January, 2006	Fuel Cell OFF (Set back to ON position on Jan 15th)
February	Fuel Cell ON (Net metering)
March	Fuel Cell ON (Net metering, Power Tower switched ON March 23rd)
April	Fuel Cell ON (Net metering)
May	Fuel Cell ON (May 20th, switched to Bypass)
June	Fuel Cell OFF (June 5th), Bypass
July	Fuel Cell Removed (July 27th), Bypass
August	Bypass
September	Grid Feeding Power Tower, Power Tower Feeding Loads
March, 2007	15kW Generator ON
May	Equipment Removed

Lessons Learned

- Edge of grid residential application successfully proven
- Battery energy storage system worked as designed
  - Round trip efficiency of approximately 39%
- However, several power quality issues emerged
  - Load shedding relay caused 2 cycle interruptions
  - Inverter operation of Power Tower in combination with a weak grid caused severe voltage flicker that caused homeowner to put system into bypass on numerous occasions

Flicker Problem

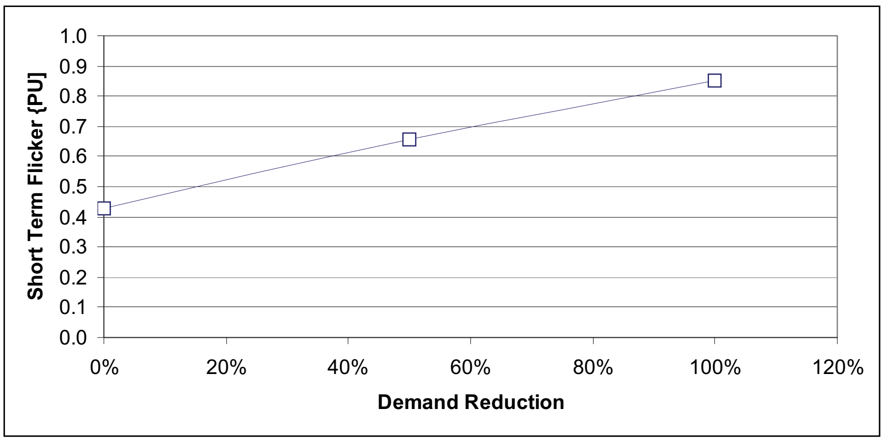
- After operating for a while the house owner started to complain about flicker in his light sources
  - Local project manager could not see any flicker
  - Lead project manager could not see any flicker
  - Gaia technical service engineer could see flicker
- Anecdotally the flicker was worse when energy storage was powered by fuel cell, but still present when energy storage powered by utility
  - House owner did not see any flicker when energy storage was bypassed



Gaia Test Results

- The grid at the test side was measured to have a short term flicker around 0.5
- Introducing the energy storage device increased the flicker with more than 80% on the input side and an additional 3% on the output side
- Using the fuel cell as source increased the flicker with 13%

Energy Source	Energy Storage	Short Term Flicker	
		Before Energy Storage	After Energy Storage
Weak Grid	No	0.47	Not Active
Weak Grid	Yes - Demand Reduction	0.87	0.90
Fuel Cell	Yes - Demand Reduction	0.95	0.97



Conclusions

- Introduction of an energy storage device used for demand reduction (current source) increased the short term flicker at a residence
- The magnitude of the short term flicker was a function of the "strength" of the source and of the level of demand reduction
  - A weak source increased the flicker
  - Increased demand reduction increased the flicker
- When used as voltage source the energy storage device had short term flicker values significant lower than the grid
  - Using the fuel cell as a DC source rather than an AC source would most likely have solved the flicker issue

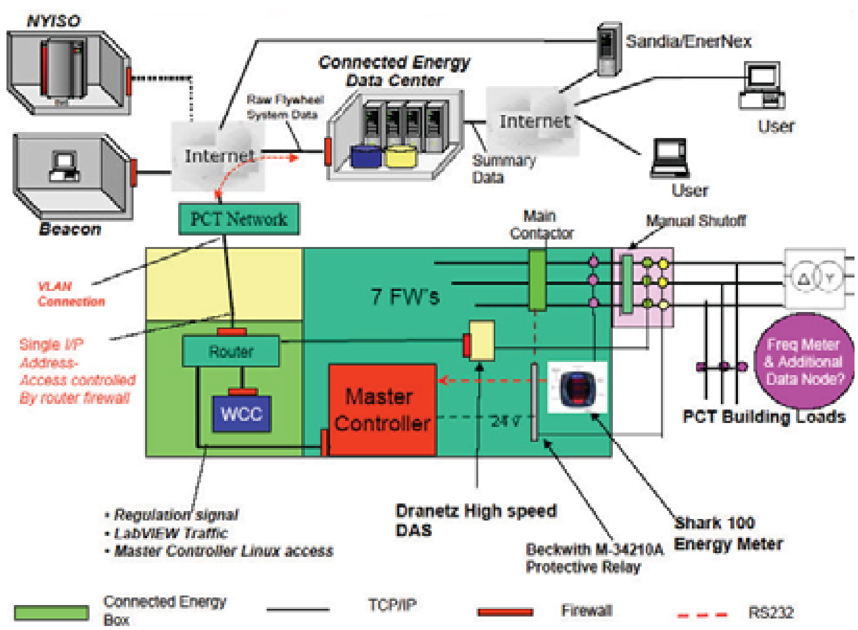
Site 2 - Beacon Power

For the Beacon Power installation, the energy storage system used in this demonstration project is a scale-power Smart Energy Matrix designed and manufactured by Beacon Power. The unit was installed at PCT in Amsterdam, NY, during the first week of June, 2006. The system consists of seven four-rotor flywheel units. The system operates at 480Vac and is capable of supplying up to 100 kW for fifteen minutes. An extensive data acquisition system has been installed by Beacon Power. Prior to June, the service entrance of the facility was monitored for approximately three months. Monitoring was concluded in March, 2007. The goal of this energy storage project was to see if the Smart Energy Matrix flywheel system could respond to changes in frequency by either injecting or absorbing power from the grid. The last week of July was used as the test signal. The frequency during this week was recorded and is being played back over and over again to view the response and operation of the flywheel. Overall, Beacon Power has proven that they can follow a frequency signal and can inject or absorb power as needed as long as the power is available.

Timeline

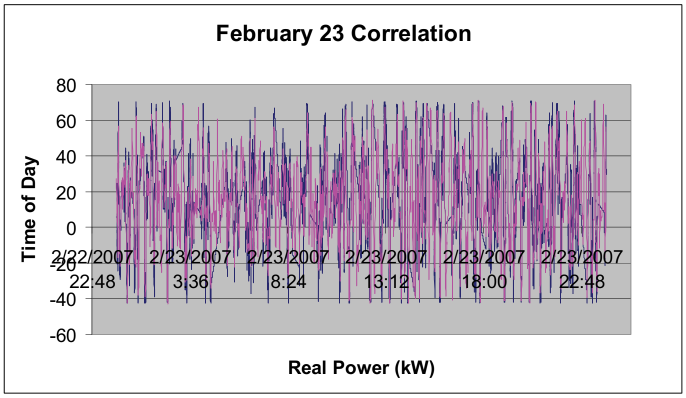
- Service entrance monitored at PCT, Amsterdam, NY from Feb – June, 2006
- Smart Energy Matrix (EM) flywheel system installed in June
- Approximately 1 month of system commissioning and testing
- Monitoring continued through March, 2007 when it was agreed enough data had been collected

DAS Block Diagram

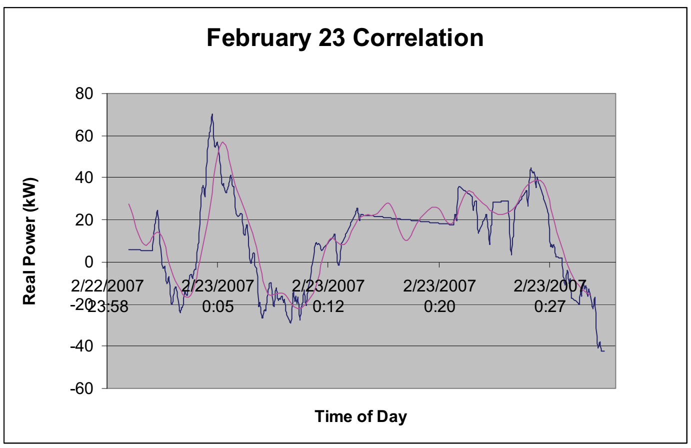


Status

- Dranetz was used to verify extensive on board DAS supplied by Beacon Power

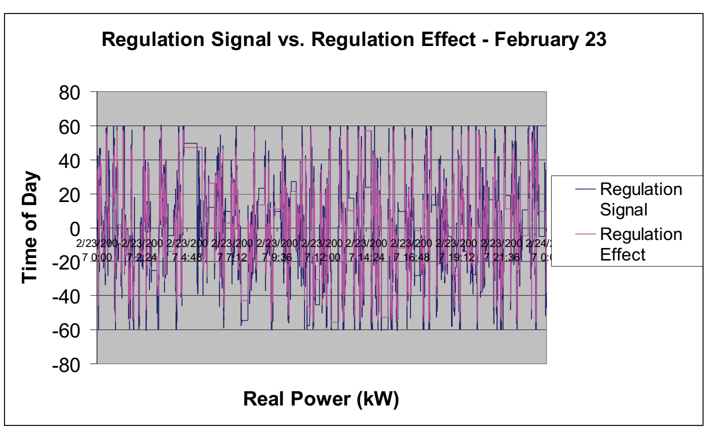


- February 23 verification correlation



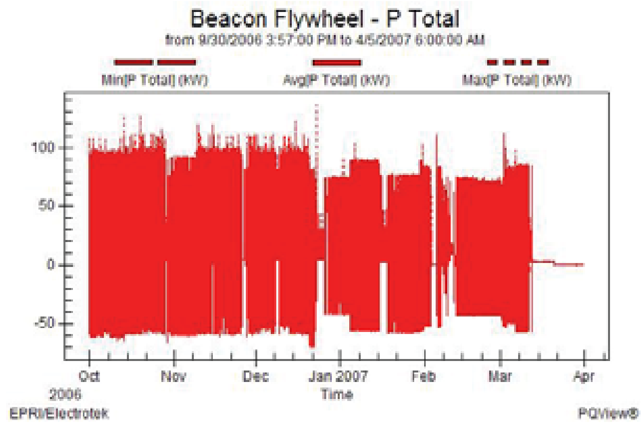
Lessons Learned

- Beacon Power has successfully shown that the EM flywheel system can react to a frequency signal and inject or absorb power as needed assuming energy is available from storage system

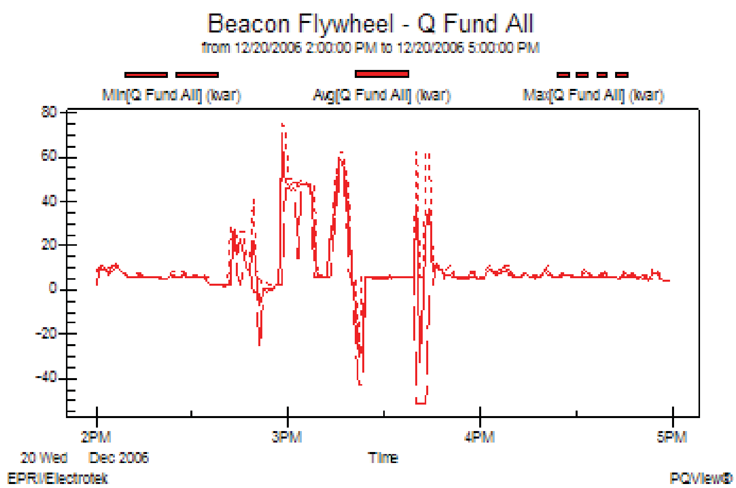


- One thing to note is

that for example on February 23, only 4 of the 7 flywheels were in operation limiting the output power to 60 kW.



- As an additional benefit, Beacon Power was able to show that the flywheel system could be used as a reactive power compensation device.



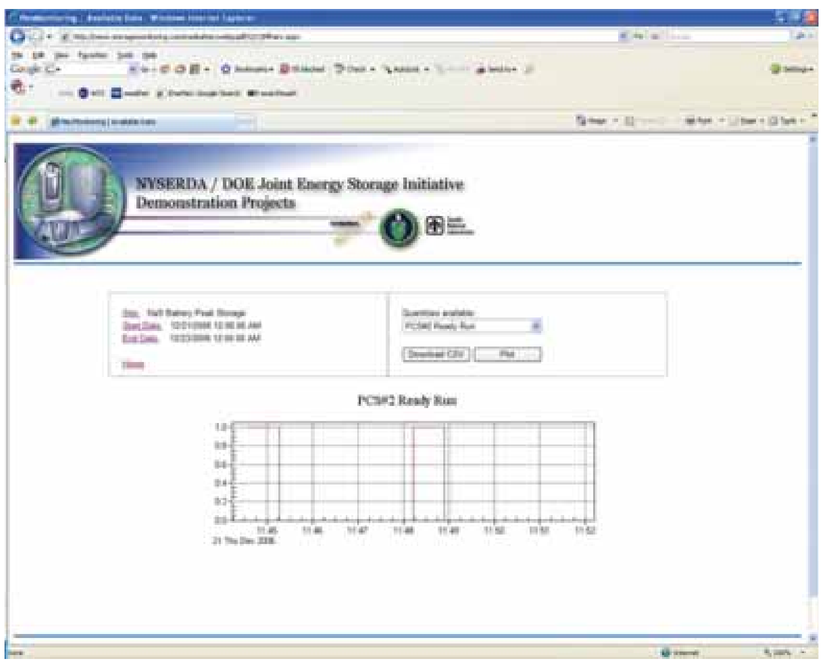
Site 3 – New York Power Authority/ABB

The NAS battery project demonstrates the utilization of a sodium-sulfur (NAS) battery system to shift compressor peak load to off-peak capacity and provide emergency backup power at a Long Island Bus depot facility. The primary application will be to supply up to 1 MW/7.2 MWh of power to a natural gas compressor for six to eight hours per day, seven days per week, especially during the summer peak period. The natural gas compressor provides fuel for buses that will replace diesel-powered buses. The NAS batteries are being supplied by NGK Insulators of Japan. ABB is supplying an on-site data acquisition system that will sample a variety of parameters at 1 second intervals and will be able to store up to 365 days worth of data. The signal list was finalized by ABB and the project team on July 10th, 2006. It is expected that system commissioning will occur in late 2007.

Signal
Grid RMS Voltage
Grid RMS Current
Grid Real Power
Grid Reactive Power
Grid Apparent Power
PCS Real Power
PCS Reactive Power
PCS Apparent Power
Load Real Power
Load Reactive Power
Load Apparent Power
PCS Real Energy Accumulated – Absorbed Real Energy
PCS Reactive Energy Accumulated – Absorbed Reactive Energy (Inductive)
PCS Real Energy Accumulated – Discharged Real Energy
PCS Reactive Energy Accumulated – Discharged Reactive Energy (Capacative)
System Charge / Discharge Cycle Counter
System Operational Mode

Status

- The process for retrieving, converting and posting the data is complete.
- We are waiting for input on what data is restricted.
- We are ready to go as soon as data becomes available.



Site 4 – Gaia Power Technologies/Princeton Power

- Gaia and Princeton Power are in production for four 75kW/225kWh Power Tower units.
- The project will demonstrate peak shaving at an industrial customer in the DCEC territory.
- Kickoff meeting was held on June 26.
- DAS configuration is expected to be similar to the NYPA/ABB project at LIBUS.

For information on other
NYSERDA reports, contact:

New York State Energy Research
and Development Authority
17 Columbia Circle
Albany, New York 12203-6399

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info@nyserda.org
www.nyserda.org

Grid Frequency Regulation by Recycling Electrical Energy in Flywheels

Final Report 08-06

State of New York
David A Paterson, Governor

New York State Energy Research and Development Authority
Vincent A. DeIorio, Esq., Chairman