

Web-based Energy Storage Monitoring – 2006 -2007 Results

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Overview

A key component in quantifying the success of an energy storage demonstration project is the acquisition of relevant system performance data. Accurate, relevant data improves public perception of the project, enables more accurate economic assessments, and provides a quick, effective means of determining the demonstration system's performance, availability, and reliability. This paper describes the work done to design a website for the DOE/CEC Collaboration that allows authorized users to query project data online. Additionally, data acquired in 2006 and 2007 will be described for one of the Collaboration's projects—a flywheel-based frequency stabilization system designed to dynamically absorb and deliver power in response to a control signal from the operating utility.

Acknowledgements

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Energy Storage Demonstration Website

EPRI developed the website for the DOE/CEC Collaboration as a portal that will allow the public to access information about each of the sponsored projects. Additionally, authorized users have password-protected access to system performance data and analytical tools. The Collaboration home page (shown in Figure 1) is located at <http://www.energystoragedemo.net/cec/> and includes links to each project. Each project has its own 'main' page that includes electrical configuration information (one-line diagrams), summary status pages, and a link for accessing the protected information. For example, Figure 2 shows real-time status information for the frequency regulation flywheel ESS.

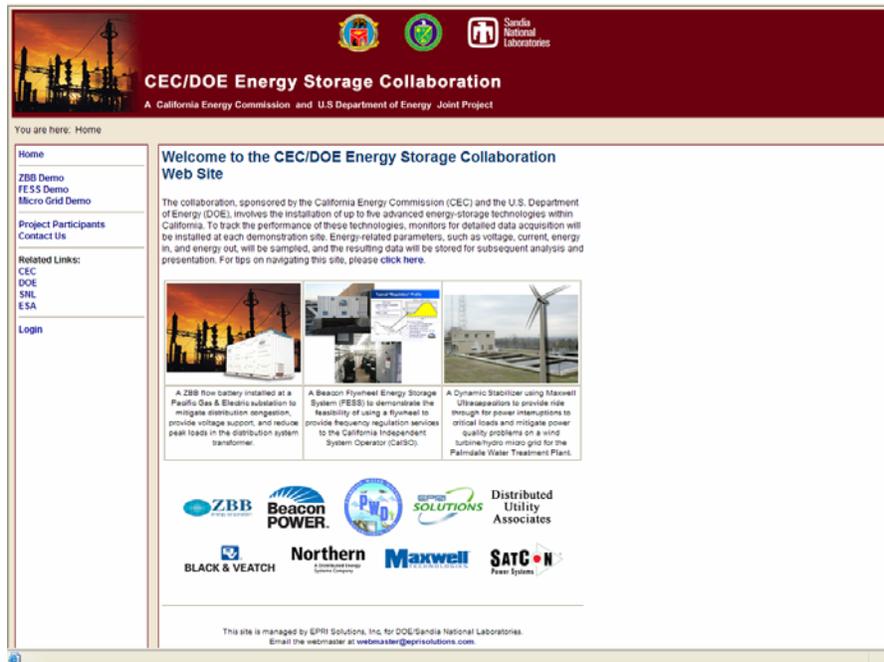


Figure 1. CEC/DOE Energy Storage Collaboration home page.

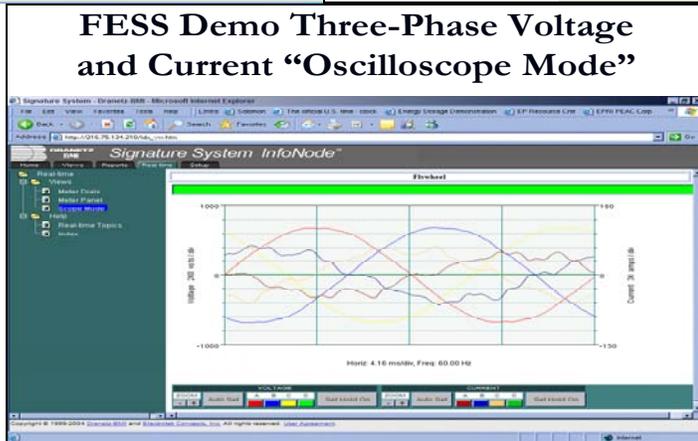
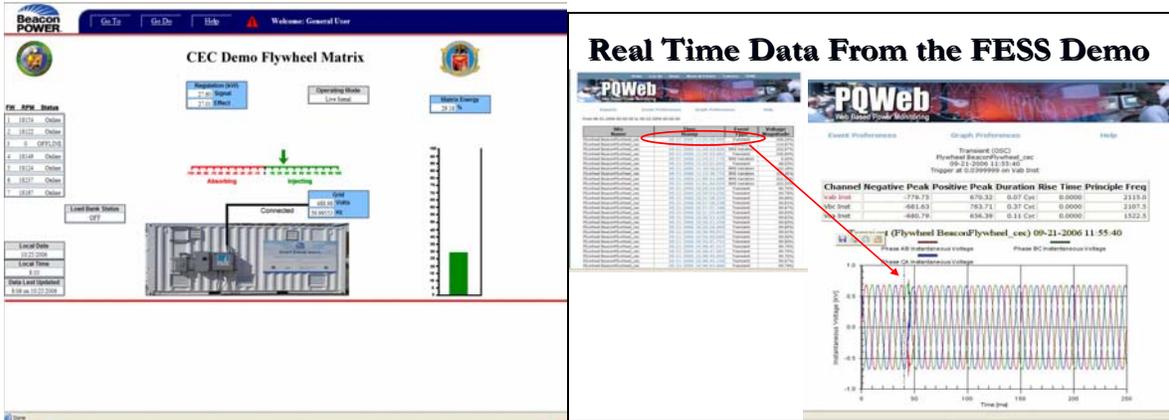


Figure 2. Web-based access to real-time system data.

Flywheel-based Frequency Regulation

California’s independent system operator (ISO) has indicated that, if fast responding regulation systems were added in significant quantity to the electric power grid, the total amount of regulation services required would be reduced. Flywheels can quickly inject or absorb power (in response to signals from the Regional Transmission Operator), but have a net zero power consumption. Thus, flywheel-based energy storage is an attractive alternative to traditional generators, because the flywheel ‘recycles’ electricity from the grid (stores it when generation exceeds loads; discharges it when load exceeds generation), rather than attempting to constantly adjust generator output to meet demand. Indeed, when aggregated to reach appropriate output/input levels, a fast-responding ESS offers other potential benefits to the electric grid:

- **Increased Available Energy** – Because present day generators need to be operated below their maximum capability to provide regulation, they are not available to provide their maximum power. Typically generators need to be below their maximum capacity by twice the amount of regulation, in order to provide ‘headroom’ for safe operation. If all regulation were accomplished by a fast-response system, then there would be an additional 2-4 % generation capacity without adding new generators.
- **Support Distributed Generation with Local Voltage Support** – Several demonstrations have already shown the benefits of using flywheels for local voltage support including a project on the New York City transit system, where ten 1.6-kWh flywheels provided voltage support between train stations. As storage increases, the feasibility of larger scale application of fast-response systems for local voltage support will be more practical.

Once deployed in significant numbers, these fast-response systems can offer additional advantages:

- **Reduced emissions** – based on reduced fuel consumption for generators
- **Increased planning flexibility** – modular, more easily deployable equipment
- **Reduced energy requirements** – for frequency regulation services

Flywheel-based ESS

For this demonstration, Beacon Power provided an ESS comprising seven 15-kW flywheels in parallel to demonstrate a 100-kW power injection level with a 20-minute discharge duration. The parallel configuration of flywheels is known as a Smart Energy Matrix (SEM). The SEM closely follows the regulation signal with a response of four seconds or less. Unlike generation-based frequency regulation, no fuel is consumed and no emissions are generated. The system was installed at the Pacific Gas and Electric (PG&E) Distributed Utility Integration Test (DUI) Facility in San Ramon, California, to demonstrate the system's ability to respond to frequency regulation signals from an ISO and to inject power to, and absorb power from, the grid.

The demonstration system comprises a flywheel array and motor/generator drives. For each flywheel, two bi-directional inverters are connected back-to-back to convert the high-frequency output/input of the flywheel into regulated 480-V, 60-Hz input/output that interfaces with a common AC bus. A step-up transformer is used to increase the between the AC bus and the grid to bring the 480-V bus voltage up to the grid's (much higher) distribution line voltage (*i.e.*, 35, 69, 115 kV). Each flywheel module is associated with an electronic conversion module (ECM) that includes a set of inverters and associated controllers. One inverter converts the variable speed output from the flywheel motor/generator to a DC bus. The second inverter converts the DC bus back to a constant 60 Hz at 480 V_{ac}. The seven ECMs operate in parallel and either charge or discharge the flywheels at a power level as directed by the signal input to the master controller. A block diagram of the system is shown in Figure 3.

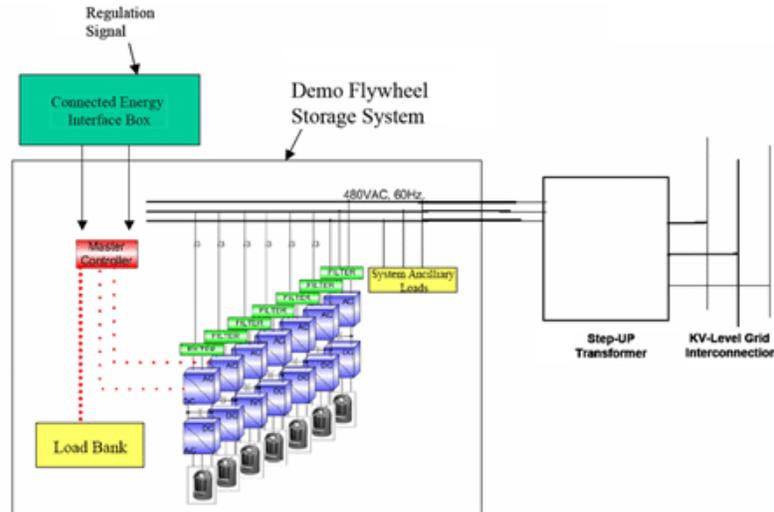


Figure 3. Flywheel-based frequency regulation demonstration system.

Performance Monitoring

Data acquisition and performance monitoring objectives for the project were as follows:

- Provide a website to display general system information related to the demonstration project.
- Supply a means of displaying and analyzing the actual electrical and availability performance data.
- Analyze the system's actual performance and availability data for the duration of the demonstration.

Key to this effort was to achieve an unbiased analysis of the system's electrical performance, independent of the manufacturer-reported information. Ideally, the results would confirm each other in terms of the power and availability performance, but would not require duplicating the entire data acquisition system. Consequently, EPRI installed a Dranetz/BMI Signature System power analyzer, which was controlled by EPRI throughout the duration of the demonstration. The Dranetz system independently 'captured' the following components of system operation and performance:

- **System Status**—confirms reported online/offline system status
- **Three-phase Power Injection**—meters this parameter and graphs the min, max, and average results at one-minute intervals (as shown in Figure 4).

- **Voltage and Current Distortion**—monitors voltage and current distortion during inject and absorb modes to quantify the worst-case levels and confirms that the system is designed well within IEEE 519 recommended values for voltage and current distortion.
- **Power Quality**—monitors the waveform resolution, which allowed EPRI to distinguish between flywheel-system-related trips and power system variations that resulted in an IEEE 1547 protective relay trip. The ‘1547 related trips’ were removed from the database before calculating the system availability.
- **Number of Flywheels Available**—time-stamped, three-phase power data allows a direct comparison of the flywheel output to the applied regulation signal to confirm the reported individual flywheel status anytime the regulation signal calls for a power level beyond the minute-to-minute system capacity.
- **Regulation Signal Match** —confirms the Beacon-reported match to the ‘effective’ regulation signal, both in percent of signals matched minute-by-minute and in actual power level.
- **Confirmed Response to a Change in Regulation Signal**—uses an external software trigger to capture waveform resolution data when the regulation signal changed from inject mode to absorb mode and vice versa.
- **System Response to a Signal Change**—observes the cycle-by-cycle response and ‘ramp rate’ for the first half-second during directional change commands from the ISO signal

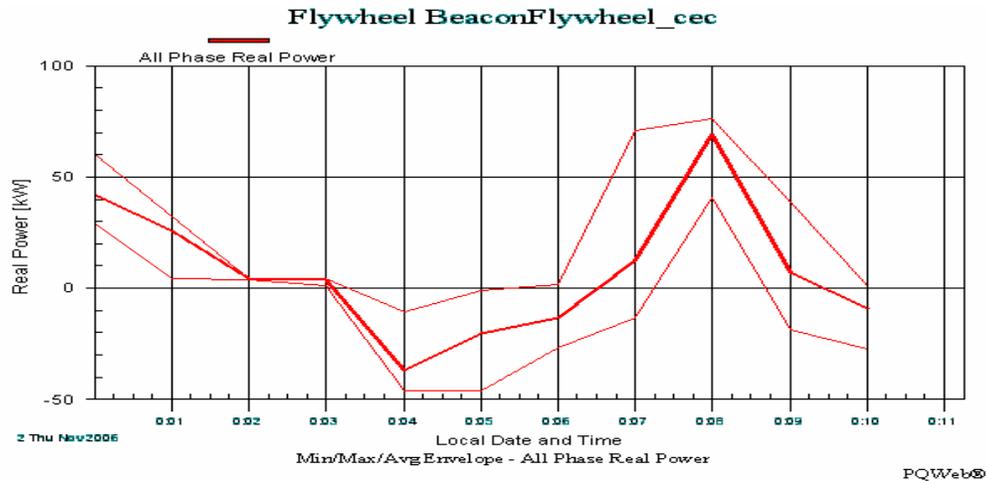


Figure 4. Three-phase power injection in 1-minute increments (11-02-2006).

In addition to EPRI’s Dranetz system, the system had an on-board power meter (the ‘Shark’). An example of the power injection and absorption data available on the website can be seen in Figure 5, where data is graphed for both power meters. The devices’ results correlated to within 0.2 percent at the full 100-kW rating. Figure 6 shows the oscilloscope resolution of the power monitor. The monitoring system provides the user with a means of capturing relevant data in resolutions sufficient for any type of analysis or diagnostic.

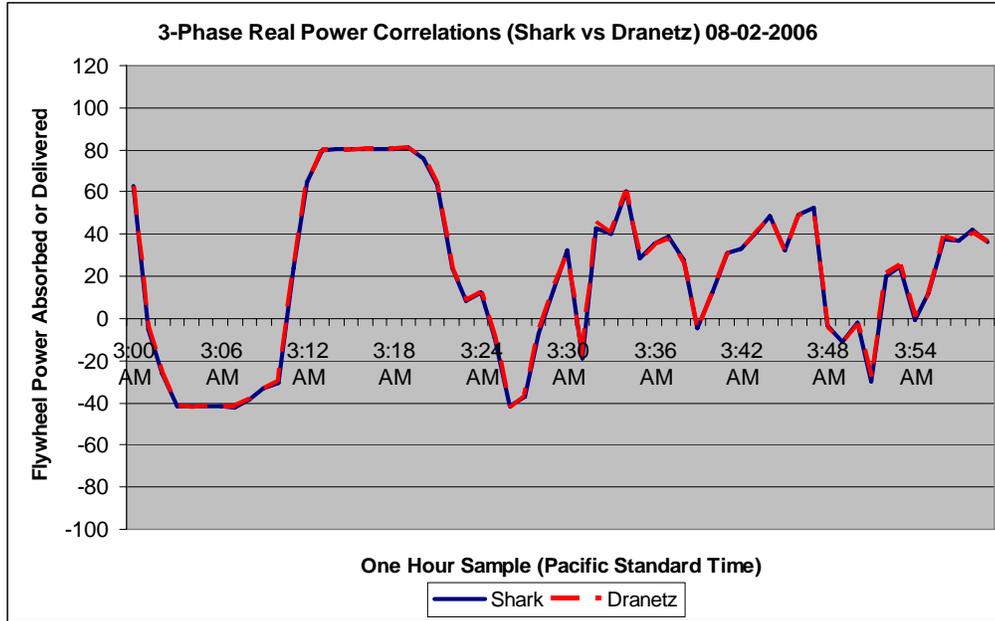


Figure 5. Data for the Shark and Dranetz energy meters (08-02-2006).

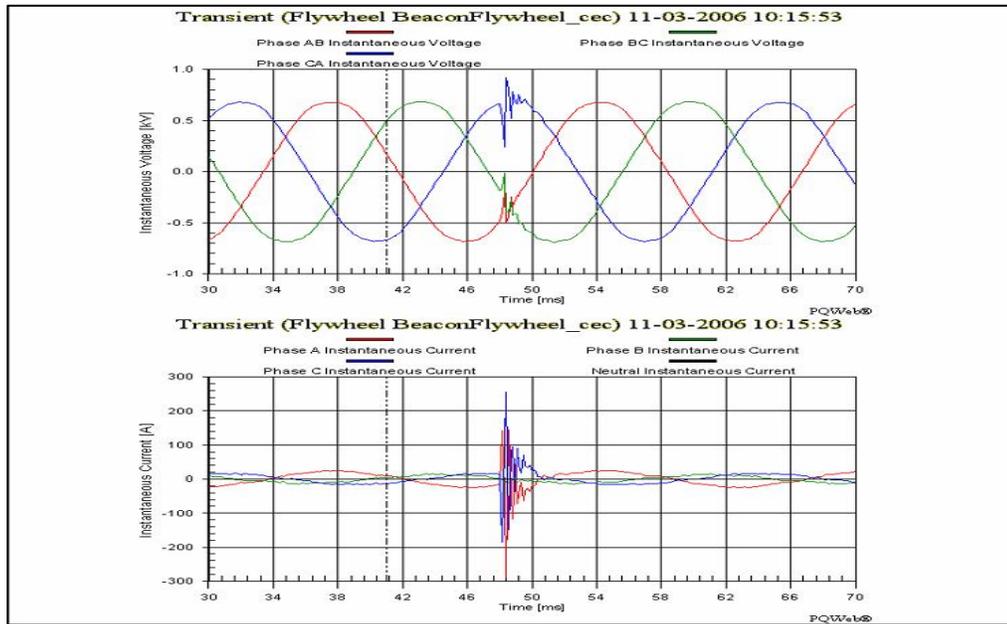


Figure 6. Example of the power meter’s high resolution scope mode analytical capability. This type of variation on 11-03-2006 may have been either a capacitor switching transient on the utility system or may have been caused by the load relay switch in the system. Because the current did not go to zero after the variation, it is clear from the plot that this variation did not cause the system to trip off line.

System Performance Summary

The system’s operational performance (relative to full rating) for August to December 2006 is summarized in Table 1. The ‘Availability at Rating’ was interpreted based on the assumption that each of the system’s seven flywheels provides up to one-seventh of the full system capacity. To determine availability, the total number of demonstration days (144) was multiplied by 24 hours per day to yield (3456) ‘Period Hours’, which was used to calculate the respective percentage of time that seven flywheels were available, that six were available, five

available, etc. If any one of the flywheels was offline for any reason (other than a fault on the power system outside of IEEE 1547 limits) that flywheel was considered unavailable for a minimum of one hour or until the monitoring systems indicated that the flywheel was back on-line. Based on this analysis, the system was available to absorb or inject power (at least one of the seven flywheels operational) during the demonstration 96.5% of the demonstration period and the system was available at full capacity (all seven flywheels operational) 47.3% of the time.

Table 1. Flywheel Output Levels (derived from all seven flywheels)

	Totals
Aggregate hrs flywheels were not available	2750
Total hrs flywheels could have been available	24192
Projected annual system availability (used to calculate MWhrs)	88.6%
Percent of time out of energy	2.50%
Percent of time communication signal unavailable (144hrs)	4.17%

Flywheel Status	All 7 Available	6 of 7 available	5 of 7 available	4 of 7 available	0 available
Hrs not Available	1822	1634	421	149	119
Period Hrs	3456	3456	3456	3456	3456
Hrs Available at Rating	1634	1822	3035	3307	3337
Availability at Rating	47.3%	52.7%	87.8%	95.7%	3.5%
System Energy	100% Capacity	86% Capacity	71% Capacity	57% Capacity	Zero Capacity

Conclusion

For the duration of the demonstration (August through December 2006), the flywheel ESS met each of the intended demonstration objectives including:

- Demonstrating the system’s ability to absorb and deliver energy at power levels meeting the 100-kW specification;
- Demonstrating the system’s ability to follow an externally generated regulation signal and respond to that signal in a timeframe that met the four-second design specification;
- Demonstrating that multiple flywheels can be paralleled in a single system and that such systems should be scaleable; and
- Demonstrating the ability to remotely acquire monitored data for system troubleshooting and historical performance analysis.