Evaluating Value Propositions For Four Modular Electricity Storage Demonstrations In California

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Background
This paper documents an evaluation of benefits and costs comprising value propositions for four modular electricity storage (MES) demonstration projects in California. These projects are part of a concerted collaboration by the California Energy Commission (CEC) Public Interest Research (PIER) Program and the U.S. Department of Energy (U.S. DOE) Energy Storage Systems (ESS Program) managed in cooperation with Sandia National Laboratories (SNL).

The value proposition analysis described herein was performed by Distributed Utility Associates, Inc. (DUA). It was sponsored by the DOE and managed by SNL. The analysis requires use of demonstration plant performance data provided, also under contract to DOE, by the Electric Power Research Institute’s (EPRI) Power Electronics Applications Center (PEAC). (EPRI/PEAC gathers, collates and verifies performance-related data collected from the demonstration plants during operation.)

Demonstrations were selected using a framework with the value proposition to be demonstrated as the primary selection criterion (a value proposition is defined by total benefit less total cost). Indeed, one of the most important facets of this collaboration between the U.S. DOE and CEC/PIER is the emphasis on benefits rather than applications and on value propositions rather than technology. Results to date indicate that flywheels show significant promise for area regulation. The on-site generation integration value proposition seems technically viable if the MES system performs as intended. No reportable benefits-related results are available for the light rail and T&D deferral demonstrations.

Energy Storage for Light Rail in Sacramento
The Sacramento Regional Transit Light Rail system experiences voltage sags – to as low as 570 VDC on the 800 VDC (nominal) system during peak demand periods, especially when trains are delayed and multiple trains are in proximity. System shutdown occurs when voltage is below 525 VDC, and acceleration decreases notably if voltage is below 600 VDC. Low voltage also increases maintenance, reduces train traction, limits addition of much needed express service, and increases overall electric infrastructure requirements.

The response is a demonstration of the Siemens SITRAS® SES; a capacitor-based “static energy storage” (SES) system. Key participants include the Sacramento Regional Transit District (RT), Sacramento Municipal Utility District (SMUD), California Energy Commission (CEC), Siemens Transportation Systems (STS) and DOE/SNL. Based on initial technical analysis results, SES installed at the selected site is expected to provide up to 65 VDC increase in minimum voltage.

Another key benefit, not related to voltage, is reduced need and cost for electric energy because energy can be absorbed/stored during train braking, for use when energy is needed for train acceleration. Energy savings are an estimated 55 kWh per hour of operation at during peak service and 35 kWh per hour off peak, or 286 MWh per year for a cost reduction of about $25,000. Current plans are for the SES to be fully operational for 15 months beginning summer 2008.

Flow Batteries for Utility T&D Deferral
Another value proposition entails reducing electric utility cost-of-service by deferring expensive transmission and distribution (T&D) upgrades. The storage technology to be used is ZBB Corp.’s zinc bromine battery Z-BESS system.

The only benefit to be demonstrated is annual cost (revenue requirement) avoided because batteries are used to defer expensive T&D upgrades. Other, less significant, benefits may also accrue when storage is used for T&D deferral.

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No specific site has been selected for the demonstration, so the actual benefit cannot be determined. Generic values are shown in Figure 1. In that figure, there are plots for various storage portions, that is, the portion of peak load to be served by storage. Plotted on the X Axis is the cost per kW of nameplate rating for T&D capacity. The resulting deferral benefit per kW of storage is shown on the Y axis. A fixed charge rate is used to estimate annual carrying charges (a.k.a. annual revenue requirement for a utility) for equipment installed.

As an example, if T&D equipment cost $1 Million to buy and install (installed cost), then a fixed charge rate of 0.13 means that the annual cost to own the equipment (utility revenue requirement) is 0.13 * $1 Million = $130,000. T&D Upgrade Factor refers to the amount of load carrying capacity added when the T&D upgrade occurs. An example of the 0.33 value used – a typical value – is an upgrade of a 12 MW T&D node so it can serve 16 MW. The 4MW added / 12 MW existing = 0.33.

Assuming storage portions of 2% to 4% for T&D, costing $50/kW to $75/kW installed, the single year benefit for storage ranges from about $200/kW to $600/kW. Though somewhat uncommon, T&D costs exceeding $75/kW installed do exist.

Pacific Gas and Electric (PG&E) will use the battery for deferral after it is tested in grid-connected mode at DUA’s Distributed Utility Integration Test (DUIT) facility, hosted by PG&E, in San Ramon, California. The testing is designed to demonstrate the system’s performance and reliability before it is used in the field.

Specifically, the test protocol involves operation of the battery for forty consecutive days “without failures or intervention” to represent operation of the battery for T&D deferral for three service years. Included are testing: a) of the zinc bromine battery’s “power overload” capability (ability to discharge for short periods at more than nominal rating), b) of “over discharge” operation involving energy needs that exceed stored energy, c) for 15 days when the battery will be discharged as if energy required equals the energy stored (normal operation), d) for 15 days during which the battery will be partially discharged, and e) of the battery’s ability to remain fully charged, without being discharged for several days. The battery will respond to PG&E substation load profiles that are scaled to represent the magnitude of actual loading.

**Supercapacitor for Generation Integration at Water Treatment Facility**

Another demonstration sponsored under the auspices of the CEC/DOE collaboration is a 450 kW (20 to 60 seconds) storage system, comprised of Maxwell Technologies ultracapacitor modules, located adjacent to the Palmdale, California Water District facility.

The system, designed and installed by Northern Power Systems, is intended to allow “enough time to bring a backup generator on line and avoid any interruption in power at the Palmdale facility” when grid power is interrupted. The system is also designed to “provide continuous power quality improvement in the form of voltage support, power factor correction, harmonic dampening, and transient mitigation” and to “facilitate integration of backup [and other onsite] generators [and to] enable easy integration of DG [distributed generation].”
The system controls and remote monitoring capability allow for optimized use of existing power sources, including an 800 kW Diesel fueled backup generator, a 250 kW hydroelectric plant, a 200 kW natural gas combustion turbine, a 250 kW Fuel Cell Energy Model DFC 300A molten carbonate fuel cell, and a nearby wind turbine rated at 950 kW. A key result will be characterization of how the energy storage system interacts with the local distribution system during power disturbances.

Flywheel Energy Storage for Utility Grid Regulation

The first demonstration completed under the CEC/DOE collaboration was the Beacon Power Corporation (Beacon Power) flywheel energy storage system used to provide area regulation. (Area regulation is a utility “ancillary service” that involves absorbing or injecting relatively small amounts of energy into the grid to offset moment-to-moment differences between power supply and demand in the specified area, often a state or several contiguous states.). The demonstration was performed at DUA’s Distributed Utility Integration Test (DUIT) facility, hosted by PG&E, in San Ramon, California and cosponsored by CEC/PIER.[3]

The sole benefit evaluated was revenue received for providing area regulation. The California Independent System Operator (CAISO) – the responsible agency for area regulation – defines the regulation service as follows: increased or decreased use of generation equipped with governors and automatic generation control to maintain minute-to-minute generation/load balance within the control area to meet North American Electric Reliability Corporation (NERC) control-performance standards. CAISO defines regulation in terms of generation: the portion of a generating unit's unloaded capability which can be loaded, or loaded capability which can be unloaded, in response to Automatic Generation Control signals from the CAISO's energy management system control computer. Regulation is used to provide control area balancing, frequency bias and time error correction.

Storage provides “up” regulation by discharging energy into the grid, and storage provides “down” regulation by absorbing energy from the grid. Notably, the rate of power from (or into) flywheel storage can change quite rapidly, whereas output from conventional regulation sources – primarily thermal generation plants – changes slowly. Generation plants’ output (up or down) changes by percentage points per minute whereas flywheels’ output can change from full output (discharge) to full input (charging) – and visa versa – within a few seconds.

Annual price for up regulation service and for down regulation service from the CAISO are shown graphically in Figures 2.A and 2.B. Annual average prices used for the valuation are $21.48/MW and $15.33/MW per service hour for up and for down regulation respectively, for a total of $36.70/MW per service hour.

![Figure 2.A Up Regulation Hourly Prices](image1)
![Figure 2.B Down Regulation Hourly Prices](image2)

Demonstration results are shown graphically in Figure 3, below. The left axis shows units of $/kW in year 1. Those units reflect a single-year amount, in the first year, for each kW of plant rating. Annual cost reflects an annualization or annuitization factor (a.k.a. fixed charge rate) of 0.2 used to estimate annual capital plant carrying charges. (That factor is multiplied by the plant installed cost to estimate annual cost.) The axis on the right side of Figure 3 indicates the corresponding lifecycle value over ten years, using a discount rate of 10%.
Results (plots) reflect three levels of annual average power output at 71%, 86%, and 100% of plant rating. (Note that 71% represents 5 of 7 flywheels in the demonstration system, 86% represents 6 of 7 flywheels). Results are presented, for those three plant output levels, for a range of plant annual availability levels.

Also shown is the break-even amount, reflecting the carrying cost for a commercial plant.

The uppermost plot indicates results for a plant operating at full rating. The next two plots indicate financials for a plant operating at 86% and 71% of its rating, respectively. Thicker parts (to the lower left) of the three plots reflect results from the demonstration. Endpoints on all three plots indicate financials for a plant operating at the respective portion of rated output, if the plant operates as much as a commercial plant is expected to operate (95% of the year, full load equivalent).

In the upper right portion of Figure 3, a box indicates net benefits (net of expenses, not including plant carrying charges) that would be expected for a commercial plant, where the commercial plant reflects plant installed cost and on plant performance estimates from Beacon Power. (Note that plant designers expect a 20 year service life for a 20 MW scale commercial plant, though the assumed service life for this report is ten years. To account for the difference: the present worth of additional benefits increases by about 50%).

Two key results from the demonstration are: 1) the flywheel responds robustly to area regulation control signals that vary much more frequently and rapidly than the traditional signal used to control much slower generation-based regulation, and 2) based on Beacon Power’s plant cost projections and reasonable estimates of revenue, the value proposition seems to be somewhat to quite attractive, financially. A key premise is that the “rapid response” characteristic of flywheels makes regulation provided by them twice as valuable as regulation from generation resources.

**Sources**
