Demonstration of a 2-MWh Peak Shaving Z-BESS[1]

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Abstract

ZBB Energy Corporation manufactures transportable, turnkey Zinc/Bromine Battery Energy Storage Systems (Z-BESS) for utility-scale storage applications. In May 2004, ZBB was awarded a multi-year, cost-shared contract with the California Energy Commission (CEC) Public Interest Energy Research Program (PIER) to demonstrate a 2-MWh Z-BESS as a utility peak shaving resource. This paper discusses the design and integration of the Z-BESS and the peak shaving benefits of the system.

Introduction

The objective of the CEC program is to demonstrate the benefits of utilizing battery energy storage for distribution system upgrade deferral. Four trailer-mounted 500-kWh units will be installed at a Pacific Gas and Electric Company (PG&E) distribution substation that is experiencing overload peaks of 1 to 1.5 MW during the summer months. Each 500-kWh unit, consisting of a 20-foot battery shipping container and a Power Conversion System (PCS) mounted on a flatbed trailer, will be connected to a pad-mount isolation transformer.

Phase 1 of the program involves manufacturing the first 500-kWh Z-BESS and delivering the unit to the Distributed Utility Integration Test (DUIT) site in San Ramon, California. The Z-BESS unit will be tested for 6 months under controlled conditions to establish response characteristics, control protocols and data acquisition requirements. During Phase 2, the three additional units will be assembled and delivered along with the initial test unit to the designated PG&E utility site(s) to demonstrate the overall system performance of the 2-MWh Z-BESS. The systems will either remain at one utility site for the entire demonstration period, or it may be moved to a second site for the latter half of the demonstration period. The Z-BESS will be tested at the utility demonstration site(s) for a duration of 18 months.

50-kWh Battery Module Description

The Z-BESS utilizes a flowing battery technology. Circulation pumps continuously feed reactants to the battery cell stacks where the electrochemical reaction occurs, while excess electrolyte is stored in external tanks. Detailed descriptions of the electrochemistry and the operational characteristics of the battery have been published previously. [1,2]

The building block for the Z-BESS technology is a 50-kWh battery module, consisting of three battery cell stacks connected electrically in parallel, a control system, a pair of electrolyte storage tanks and pumps

Figure 1. 50-kWh Battery Module

[1] This project is part of the Energy Storage Collaboration between the California Energy Commission (CEC) and the Energy Storage Systems Program of the U.S. Department of Energy (DOE/ESS), and managed by Sandia National Laboratories (SNL).

and plumbing for circulation the electrolyte. Each module is rated at 50kWh (dc) for a 2 to 4-hour discharge and has an open circuit voltage of 108 volts.
Recent efforts have focused on configuring the components into a vertical arrangement to minimize the footprint of the module. During the design phase, a significant engineering effort was undertaken to simplify the manufacturability of the module by dividing the major components into three separate pre-assembled sections. The lower section contains the electrolyte storage tanks, the middle section consists of the pumps and electrical control box and the upper section supports the battery stacks. Previous designs had the battery stacks positioned between a set of electrolyte storage tanks in a horizontal arrangement. The new design has reduced the footprint from 28 ft^2 to 12.8 ft^2, which has eliminated the need for a racking system to support a second level of battery modules. The redesigned module has also allowed 500-kWh of energy storage to be packaged into the same container that formerly housed 400-kWh. Figure 1 shows the sectional design of a 50-kWh module.

Figure 2. Battery Cell Stack Installation

The electrolyte storage tanks are rotationally molded from High Density Polyethylene and inserted into a structural frame that comprises the lower section of the module. The middle section consists of a second structural frame, which contains a support plate with the electrolyte circulation pumps and an electrical box for the module control system.

Self-priming centrifugal pumps with AC motors and variable frequency motor drives are used to circulate the electrolyte. A Programmable Logic Controller (PLC) in the control box coordinates the operation and safety of the module. The PLC manages electrolyte liquid levels and monitors leak sensors, voltage and temperature. The PLC monitors the performance of the module by comparing measured parameters to preset limits. If the measured parameters fall outside the preset values, the PLC will adjust variables, such as pump speeds, to compensate. The PLC also reports module data and receives commands from the battery host controller at the 500-kWh Z-BESS level.

The upper section of the module consists of a framework that supports the battery cell stacks and the associated plumbing manifold system. A key feature of the flowing battery technology is that the battery stacks, where the electrochemical reaction occurs, can be easily replaced at a fraction of the initial system cost. Figure 2 demonstrates the installation of the upper battery stack section to the main structural portions of the battery module.

500-kWh Z-BESS Description

A 500-kWh Z-BESS provides a meaningful amount of energy storage for utility applications. To achieve this, ten 50-kWh battery modules are aligned in two independent strings on each side of a standard 20 foot Military cargo container. The battery container has full side opening, bi-fold doors on both long sides to allow access to the battery modules. A string of five modules aligned on one side of a shipping container is shown in Figure 3. The battery container, PCS and cooling equipment are mounted on a 45-foot flatbed trailer for operation and transportation to site.

Figure 3. String of five battery modules aligned in battery container.

The battery modules are loaded into the container using a forklift as shown in Figure 4. The weight of one module is approximately 3,000 pounds including electrolyte.

Figure 4. Loading a battery module into the battery container.

The Z-BESS unit is rated at 500 kWh of energy storage with a continuous power rating of 250 kW that can be sustained for 2 hours. The battery can achieve higher currents with a peak power output of 500 kW, which is the rating of the PCS. Specifications for the battery are shown in Table 1.

Table 1. Battery specifications

	50-kWh Module	**500-kWh Battery Container**
DC Interface	120 Volts (dc) max 108 Volts (dc) open circuit	600 Volts (dc) max 540 Volts (dc) open circuit
Energy Capacity	50 kWh (2-4 hour rate)	500 kWh (2-4 hour rate)
Power	25 kW continuous / 50 kW peak	250 kW continuous / 500 kW peak
Configuration	Three cell stacks connected electrically in parallel	10 battery modules 2 parallel strings of 5 modules in series
Dimensions	44"W x 42"C x 78"H	20'L x 8'W x 8'6"W
Weight	3,000 pounds (estimated)	40,000 pounds (estimated)

A 500 kW/625 kVA PCS, supplied by Satcon Power Systems, is mounted to the back end of the trailer. The two-stage unit, comprised of choppers and inverter/converter, enables the bi-directional flow of power from the battery to the electrical grid. The inverter was designed for three-phase output connection of 480Vac, 60Hz operation. The DC cables travel from the PCS through conduit underneath the flatbed trailer to the battery container. Two overhead cable trays that extend from the ceiling of the battery container are used to support the DC cables, which run from one end of the container to the other.

The PCS supplies AC power to the battery container for the control system, pumps, chillers and lighting and other electrical loads. A host controller located in an electrical box at the end of the battery container controls the operation of the 500 kWh Z-BESS by managing the PCS functions, monitoring the individual modules and archiving battery data.

At the bottom of the battery container are two separate spill containment sumps that run the entire length of the container, one for each string of modules. Each sump is designed to hold the entire contents of a module in the case of a spill.

Exhaust fans at both ends of the container circulate air through the battery container. Two chillers, each rated at 2 tons of cooling capacity, supply coolant to each battery module through a heat exchanger in the electrolyte storage tanks. Coolant lines travel from the chillers, which are mounted at the front end of the trailer, through the wall of the battery container to the modules. Two sets of manifolds that run the length of the sumps are used to distribute the coolant to the individual battery modules.

Operation of the 500 kWh Z-BESS

Factory testing of the first 500-kWh Z-BESS was initiated in September 2005. The performance of the battery system is verified by performing a standard baseline cycle, which consists of charging the battery for 4.5 hours at 150 amps (each string), then discharging at 150 amps until the battery reaches 60 volts (1.0 volts per cell). The cut-off point for a string of battery modules occurs when any module in the string reaches 60 volts during discharge. During a complete baseline performance cycle, the unit discharged for nearly 4 hours and achieved energy output in excess of the 500 kWh (dc) rating. Voltage profiles for the two battery strings during a baseline cycle are shown in Figure 5.

The battery can be charged or discharged at constant current or constant power. The system will also be able to perform load following operations by utilizing input from grid monitoring current and potential transducers (CT's and PT's) allowing real-time "peak shaving" operations.

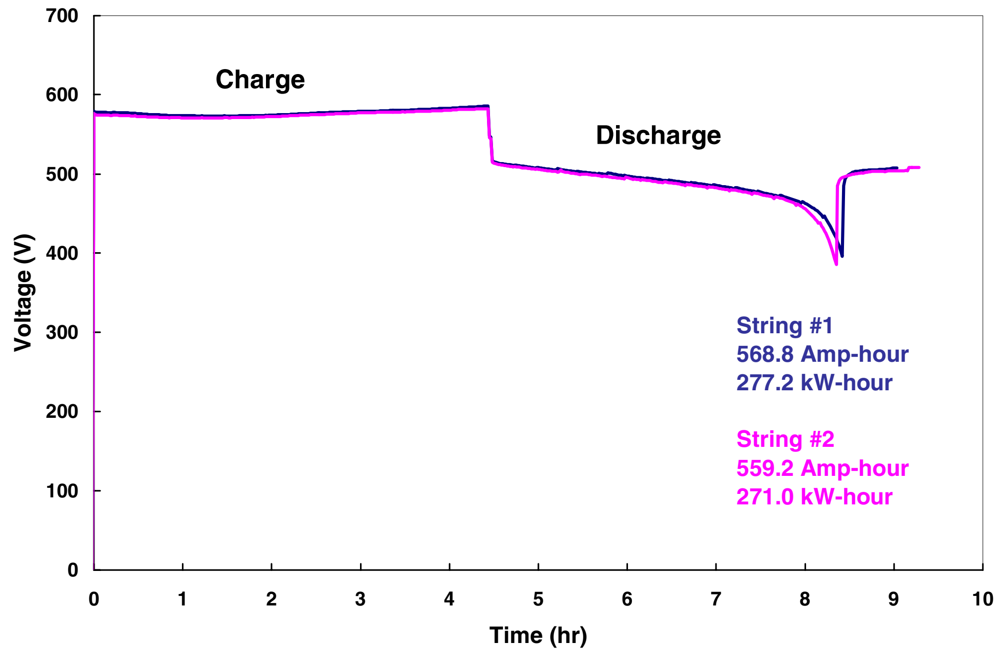

Figure 5. Voltage profiles for each string of a 500-kWh Z-BESS during a baseline cycle.

In a separate test, the AC and DC power output from a single string was measured at various output currents during discharge of the battery (See Figure 6). The difference between the AC load and the DC load is associated with the power draw from the PCS and the auxiliary equipment needed to operate the battery.

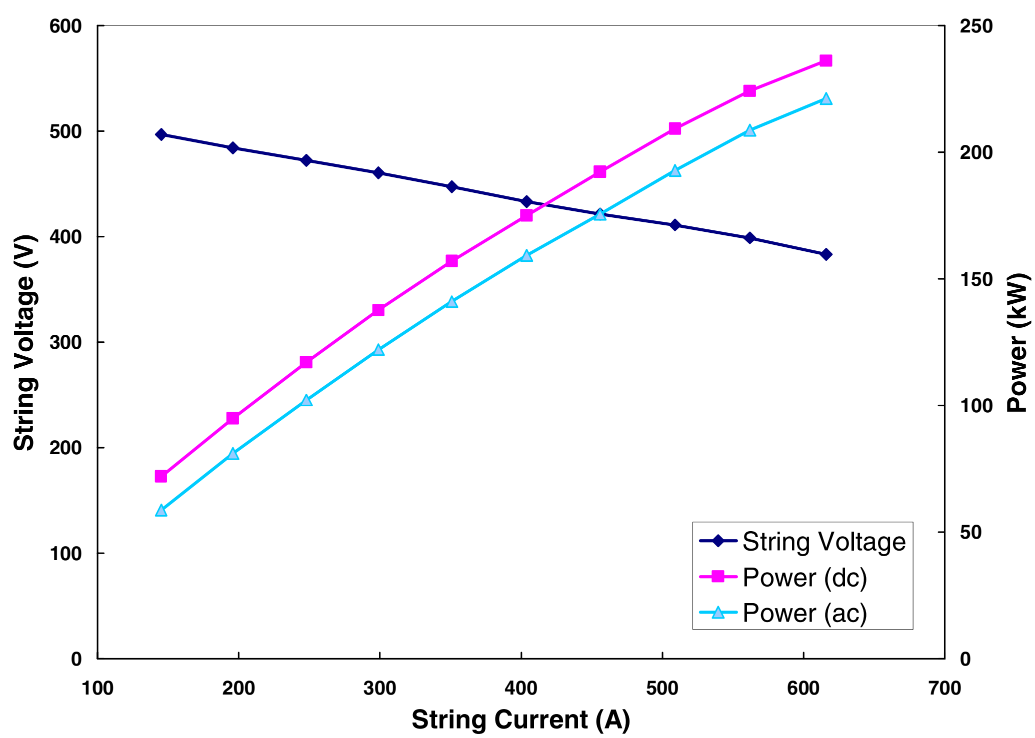

Figure 6. Power Characteristics for a 250-kWh battery string

Benefits of the Z-BESS

The viability of the technology for grid support and peak shaving applications has been validated during previous demonstration projects [3]. A 400-kWh Z-BESS successfully provided voltage stability at the end of a soft utility line at one site, and provided peak load reduction to an overloaded 800kW substation.

For the CEC demonstration project, the Z-BESS will be used to demonstrate the benefits of distribution system upgrade deferral at a PG&E substation that is experiencing peak overloads during the summer months. To accomplish this, the battery will provide the necessary peak capacity and energy to reduce the substation peaks in the electrical load.

The ultimate goal of this program is to determine the benefits of utilizing the Z-BESS for a utility peak shaving application. This includes evaluating the economic benefits of the system and monitoring the operation and performance of the Z-BESS. The key information needed for this type of evaluation is historical data from the demonstration test site as well as the availability and performance of the Z-BESS. Data will be collected to verify that the storage system operates when necessary and that it is able to provide the necessary power required by end user.

Summary

The construction of the initial 500-kWh Z-BESS will be completed in early October 2005, followed by factory testing of the unit. The first 500 kWh Z-BESS is scheduled for delivery to the DUIT facility immediately following factory acceptance testing. Three additional systems will be assembled in the next six months, and all four 500-kWh Z-BESS units will be combined to give the total 2-MWh system. The four trailer mounted 500-kWh systems will be connected to the utility at a substation location designated by PG&E.

References:

1. P. Lex and J. Mathews, “Recent Developments in Zinc/Bromine Battery Technology at Johnson Controls”, Proceedings of the 35th International Power Sources Symposium, June 1992.

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3. V. Scaini, P. Lex, T. Rhea and N. Clark, “Battery Energy Storage for Grid Support Applications”, Proceedings of the Electrical Energy Storage Applications and Technologies (EESAT) 2002 Conference, San Francisco, CA, April 15-17, 2002.