PRE-CONCEPTUAL DESIGN OF THE BOULDER CITY BATTERY ENERGY STORAGE DEMONSTRATION UNIT

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INTRODUCTION

Black & Veatch Corporation developed a pre-conceptual design for a 2.5 MW, 10 MWh Battery Energy Storage System (BESS) demonstration unit at Boulder City, Nevada[1]. The project was funded by the United States Department of Energy through a contract administered by Sandia National Laboratories. The concept of a battery energy storage demonstration unit at Boulder City has been sponsored by NEVAREST Research, a non-profit organization located in Boulder City.

Black & Veatch retained Gridwise Engineering Company of Danville, California, to perform the evaluation of advanced battery storage technologies in the context of this project.

POTENTIAL BENEFITS OF BATTERY ENERGY STORAGE SYSTEMS

Utility-scale Battery Energy Storage Systems can provide benefit through several mechanisms. A primary benefit is through load shifting, in which the BESS is charged during off-peak hours when the cost of electricity is relatively low, and the BESS is discharged during on-peak hours when the value and cost of the electricity generated are comparatively high. Figure 1 illustrates how the battery storage facility will be used to shave the peak demand for Boulder City. As seen in the figure, the actual peak load is reduced as a result of battery operation, and the batteries are recharged during off-peak periods when energy prices are comparatively low. Because the charge/discharge efficiency is about 70 percent, it takes about 1.4 kWh of charging energy to produce 1 kWh of output from the BESS.

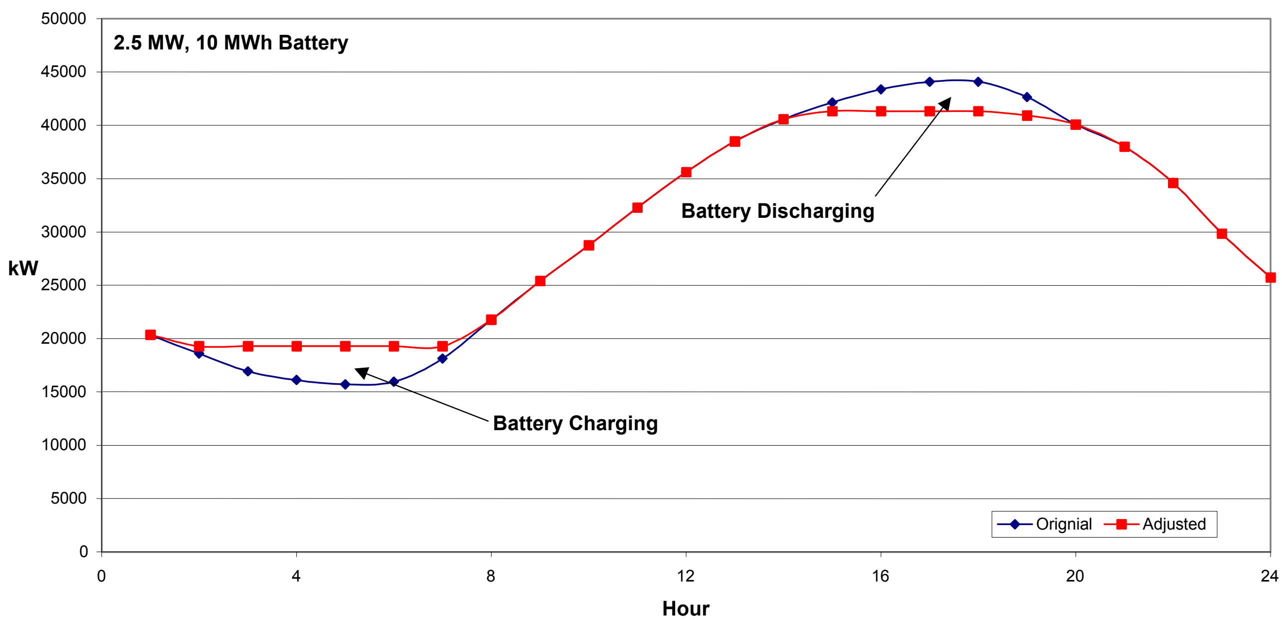

Figure 1. Sample Peak Shaving Operation for June 30, 1999.

The BESS can also provide benefits related to what are commonly termed ancillary services. Typical ancillary services include voltage and frequency support, spinning reserve, and blackout capability. In addition, a BESS may provide benefit by eliminating or delaying the need for upgrading transmission line capacity to the substation where it is located. Transmission to the substation is increased during low load hours when the transmission system is capable of handling additional load. The BESS provides supplemental power supply to the distribution system during peak hours when the transmission system may be at or near its capacity limit. This can also result in lower line losses (I^2R losses).

BOULDER CITY PROJECT CHARACTERISTICS

Boulder City ("the City") is a community with a population of about 15,000 located just west of Hoover Dam and about 20 miles southeast of Las Vegas. Originally built to house workers constructing the Hoover Dam, the City is now the residence of many federal workers employed by the United States Bureau of Reclamation and the National Park Service, as well as many residents who commute to jobs in the Las Vegas area. The electrical load for the City is primarily residential with some light commercial.

The City owns and operates a municipal electric utility, which, as a Public Power entity, has a preference status with the U.S. government. As such, it receives allocations of hydroelectric power from the Hoover and Glen Canyon Dams on the Colorado River. These relatively low cost resources are provided by the Western Area Power Administration (WAPA) and the Salt Lake City Area Integrated Projects (SLCA/IP), which comes through the Colorado River Commission (CRC). Because power (capacity) and energy from these sources is limited, the City must also purchase capacity and energy from other, more expensive sources, including Nevada Power Corporation (NPC). Purchases from non-utility capacity owned by Reliant are also possible if scheduled in advance.

The ability of Boulder City to receive its full hydroelectric allocation is dependent on water flow, and thus rainfall and snowfall each year. These hydroelectric resources were sufficient to meet the City's full load for seven months in 1999 and for four months in 2000. Purchases from NPC were required to serve the City's load in the remainder of the months,. In 1999, purchases from NPC occurred in June through October, and in 2000, purchases were made in the months of May through December.

Purchases from NPC are either through "Amendment 1" or "Schedule D." Amendment 1 purchases include a capacity charge and an energy charge. When purchases from NPC are made through Amendment 1, energy costs are relatively low. However, there is a capacity charge element that can result in high incremental costs.

Schedule D purchases are on an as-needed basis, and are priced at the NPC marginal cost. The costs can be substantially higher than the City's other resources because the rate for Schedule D energy is market-based. It is anticipated that the BESS demonstration unit will primarily displace the Schedule D purchases.

Proposed Site for the Boulder City BESS Demonstration

The proposed site for the Boulder City BESS Demonstration is adjacent to the Hemenway Substation on property owned by the City. This substation converts incoming power at 69 kV to 12.47 kV for distribution to local loads. The proposed site, which is approximately 150 ft by 300 ft, has been cleared of vegetation and is relatively level. The substation has an empty bay for future expansion, which will facilitate interconnection of the BESS to the substation. The site has ready access from US Highway 93.

EVALUATION OF BATTERY ENERGY STORAGE TECHNOLOGIES

As part of the project, Gridwise Engineering Company performed an evaluation of Advanced Battery Energy Storage technologies. Four advanced BESS technologies were considered for the demonstration project.

- Sodium Sulfur
- Vanadium Redox
- Zinc Bromine
- Regenesys®

The appropriateness of the technology to the application, the storage sizing requirements, the physical site limitations, potential safety issues, and relative acquisition and operating costs were considered for each technology. Gridwise developed a questionnaire which was sent to a number of advanced battery developers requesting information on various topics, including a request for specific information on costs for a 2.5 MW, 10 MWh demonstration plant. The following vendors were contacted concerning their battery technology.

- NGK Insulators, Ltd: Sodium Sulfur
- Powercell Corporation: Zinc Bromine
- Sumitomo Electric Industries, Ltd.: Vanadium Redox
- Vanteck (VRB) Technology Corporation: Vanadium Redox
- ZBB Energy Corporation: Zinc Bromine

Innogy Technology Ventures, Ltd., the vendor for the Regenesys® technology, was also contacted. Innogy declined to participate in the evaluation because the 2.5 MW, 10 MWh demonstration unit size is below their minimum capacity. Innogy indicated that their focus is on larger plants, such as their two 120 MWh plants under construction in the United Kingdom and the United States. Therefore, the Regenesys® technology was not included in this evaluation.

BESS Technology Readiness

A summary of technology readiness as provided by vendor responses in June of 2001 is given in Table 1. The sodium sulfur technology appears to be the most developed in terms of size and number of commercial installations, annual production capacity, and in terms of UL listing. However, the vanadium redox and zinc bromine technologies have installations of appreciable capacities, with annual production capabilities which could support the Boulder City BESS demonstration project.

Table 1. Technology Readiness

	Sodium Sulfur	Vanadium Redox	Zinc Bromine
Field Experience	Over 30 projects ranging from 25 kW to 6 MW. Largest commercial installation is 48 MWh.	Several projects, ranging from 100 kW to 3 MW (pulse power rating). Largest commercial installation is 1.5 MWh.	Several projects, from 50 kW to 250 kW. Largest commercial installation is 400 kWh.
Annual Production Capacity	160 MWh	30 MWh	40 to 70 MWh
Actual Production, Last 12 Months	50 MWh	10 MWh	4.5 MWh
UL Listing	Expected to have UL report by early 2002. Electronics would be UL listed.	Electronics only	Electronics and possibly battery

Site Layout and Footprint

A key technology consideration was whether the demonstration unit based on the technology would fit in the available land area and adhere to height restrictions. Table 2 provides key information on the physical configuration and footprint of the BESS for each of the technologies. The sodium sulfur battery would come in self-enclosed packages. The other technologies would require building enclosures. All of the technologies would fit within the site boundaries.

Table 2. Site Layout and Footprint

	Sodium Sulfur	Vanadium Redox	Zinc Bromine
Structure	Outdoor rated battery enclosures and PCS enclosures.	Building enclosure.	Building enclosure.
Footprint	About 5,000 ft^2	12,000 to 17,000 ft^2	5,000 to 7,000 ft^2

Life and Performance

Table 3 lists life and performance projections based on 100 cycles per year. There is a wide spread of life projections. Charge/discharge efficiency (AC to AC) varies from 65 percent to 80 percent.

Table 3. Life and Performance

	Sodium Sulfur	Vanadium Redox	Zinc Bromine
Life	15 years	7 to 15 years	10 to 20 years
Efficiency (AC to AC)	72 percent	70 to 80 percent	65 to 70 percent

Capital and O&M Cost Estimates

Vendors' estimates of engineering, procurement, and construction (EPC, sometimes referred to as "turnkey") costs for the 2.5 MW, 10 MWh battery energy package are listed in Table 4. The survey provided a clear listing of costs to be included, including all batteries, controls, enclosures, engineering, and construction of the BESS unit. Estimates do not include BESS interconnection with the substation or other site improvements.

Vendors' estimates of operations and maintenance (O&M) costs are also presented in Table 4. Each technology vendor indicated that no operators would be required on site. Maintenance requirements differ with the technology, with regular inspections recommended. Vendors' estimates of O&M costs varied considerably, from about $30,000 per year to $150,000 per year.

Table 4. O&M and Capital Costs			
	Sodium Sulfur	**Vanadium Redox**	**Zinc Bromine**
Operators On Site	None	None	None
Required Maintenance	Remote monitoring. Three-year inspections include retorquing terminals, collecting/analyzing OCV data, sensor calibration, system testing.	Quarterly or annual maintenance. Periodic parts replacement (pumps and fans every 5 to 10 years).	Remote monitoring, annual inspections. Specific maintenance items still to be developed.
O&M Cost	$32.5k per year	$50k per year	$30-150k per year
EPC Cost	$12 Million	$10.9 to $11 Million	$5.8 to 8 Million

PRE-CONCEPTUAL DESIGN OF BESS DEMONSTRATION UNIT

Each of the three technologies evaluated continues to be a candidate for the Boulder City BESS Demonstration Unit. Pre-conceptual designs were developed using each of the technologies using the information provided by the vendors as an EPC building block. The following items were included in the design and cost estimate.

- The BESS building block
- Electrical and control interconnections with the substation
- A Visitor Center
- Parking lot for the Visitor Center
- Indirect capital costs

BESS Building Blocks

The BESS building block in each case is assumed to be a complete package. In the conceptual design, the only difference between the technologies is the capital and O&M cost estimate based on the vendor's EPC cost estimates. Two artist's renditions were prepared: a rendition with the self-enclosed BESS, which is characteristic of the self-enclosed sodium sulfur system; and a building-enclosed BESS, which is characteristic of the vanadium redox and zinc bromine systems.

Electrical and Control Interconnections

The BESS demonstration unit will be located at the City's 12.47 kV Hemenway Substation. The substation has two 69 kV to 12.47 kV transformers fed by two separate 69 kV transmission lines. The substation has a spare vacuum circuit recloser bay, which, at the time of construction of the substation, was reserved by the City for future expansion. The spare bay will be equipped to provide the necessary substation electrical interconnections with the BESS. Controls for the relaying equipment will be housed within an existing control building.

Visitor Center and Parking Lot

A 2,500 square foot Visitor Center was included in the design of the demonstration project. The demonstration unit would be adjacent to U.S. Highway 93, which is a major thoroughfare for tourists visiting the Hoover Dam. It is estimated that 15 million tourists per year drive by the site. A Visitor Center will allow public education on battery energy storage system technology and benefits, as well as other energy programs supported by the U.S. Department of Energy, such as renewable energy. The Visitor Center would include office space for attendants and rest room facilities for visitors. The parking lot has been sized to accommodate parking of 20 automobiles.

Artist's renditions for the demonstration project including the self-enclosed and building-enclosed BESS demonstration units are shown in Figures 2 and 3, respectively. The Visitor Center is at the right of the rendition; the BESS is in the middle; the substation (surrounded by a brick wall) is at the left. The rendition for the building-enclosed BESS is based on the largest footprint identified by a Vanadium Redox vendor. The actual size could be smaller, as indicated in Table 2.

Cost Estimates

Table 5 provides a summary of capital cost estimates for the BESS Demonstration Unit for each of the technologies considered. "Engineering" included in this estimate is for the electrical interconnections, Visitor Center, and parking lot only. BESS engineering is considered to be included in the EPC estimate. Contingency for the battery systems is also considered to be included in the EPC estimates. Additional project contingency is assumed to be 5 percent for all technologies.

Figure 2. Stand-Alone BESS.

Figure 3. BESS Enclosed in Building.

Table 5. BESS Demonstration Unit Capital Costs (Thousands of Year 2001 US$)			
	Sodium Sulfur	**Vanadium Redox**	**Zinc Bromine**
EPC Battery System Cost	12,000	11,000	5,000 to 8,000
Electrical Upgrade	65	65	65
Facilities	396	396	396
Engineering and Construction Management	450	450	450
Contingency	632	612	323 to 432
Total	13,543	12,523	7,034 to 9,343

CONCLUSIONS

The following conclusions have been drawn concerning a Boulder City BESS Demonstration Unit using advanced battery system technologies.

- Each of the advanced battery system technologies (sodium sulfur, vanadium redox, and zinc bromine) remains a viable candidate.
- The site is appropriate for such a demonstration unit.
- Rough capital cost estimates for BESS demonstration units range from about $7 million to about $13.5 million.
- Vendor estimates of annual O&M cost estimates range from about $30,000 to about $150,000. We believe the $150,000 per year estimate to be high. Four of the five estimates were in the $30,000 to $50,000 per year range.

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Figures and Tables included in this paper are taken from Reference 1.

REFERENCES

1. Black & Veatch Corporation, "*Boulder City Battery Energy Storage Feasibility Study*," to be published by Sandia National Laboratories, 2002.