LESSONS LEARNED FROM THE PUERTO RICO BATTERY ENERGY STORAGE SYSTEM

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Synopsis: The Puerto Rico Electric Power Authority (PREPA) installed a distributed battery energy storage system in 1994 at a substation near San Juan, Puerto Rico. It was patterned after two other large energy storage systems operated by electric utilities in California and Germany. The Puerto Rico facility is presently the largest operating battery storage system in the world and has successfully provided frequency control, voltage regulation, and spinning reserve to the Caribbean island. The system further proved its usefulness to the PREPA network in the fall of 1998 in the aftermath of Hurricane Georges. However, the facility has suffered accelerated cell failures in the past year and PREPA is committed to restoring the plant to full capacity. This represents the first repowering of a large utility battery facility. PREPA and its vendors and contractors learned many valuable lessons during all phases of project development and operation, which are summarized in this paper.

1 Introduction

In the early 1980s, engineers at PREPA began investigating alternatives to prevent load shedding and provide frequency control. They developed a plan of action that was passed by the Governing Board on December 12, 1989. Specifically, the resolution called for:

- Increasing the availability of existing units
- Improving the load response of existing turbo-generator units
- Requiring all new combustion turbines (utility and non-utility) to provide fast spinning reserve
- Installing 100 MW of immediate-response energy storage throughout the network

In 1990, PREPA’s Governing Board gave authorization to design the first 20 MW of battery energy storage. Design, engineering, and procurement proceeded through 1992, with construction initiated in August 1992. The building was completed in October 1993, and the plant was inaugurated at the Sabana Llana substation near San Juan, Puerto Rico, in July 1994. It was patterned after two other large energy storage systems in California and Germany and is presently the largest operating battery storage system in the world. (see Figure 1).

The battery energy storage system (BESS) consists of six main subsystems:

- Batteries and auxiliaries
- Power conversion system

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Since it first began operations in 1994, the BESS has responded to dozens of load shedding events and continuous demand for frequency regulation. During initial start-up and operations, however, every key component experienced some problem. PREPA, their vendors, and contractors have solved many of these problems. Still, other challenges remain. Despite these problems, however, the BESS performed admirably in the aftermath of the worst hurricane to hit the island this century. The plant was able to maintain voltage support on the only transmission line from San Juan to the northeastern region that was still operating after the hurricane.

PREPA plans to construct a second BESS at the Sabana Llana substation, beginning the planning and design phases in fiscal year 2000 (July 1999-June 2000), with construction starting in FY 2002. PREPA served as the system integrator for the first BESS, but it is unlikely to perform that role for this second facility. PREPA is currently planning for a turnkey facility, with its performance guarantees and reduced stress on the owner during design, procurement, construction, and initial start-up. The utility, however, will undoubtedly be an active participant in this project.

2 System Functions

Energy storage systems support generation with rapid reserve and frequency control, transmission & distribution (T&D) with voltage regulation, and customers with more reliable service.

- Spinning reserve is defined as the unused generation capacity that is synchronized to the network and can respond within ten minutes to prevent interruption of service to customers (load shedding) in the event of a failure of an operating power plant.
- Rapid reserve is a portion of spinning reserve that is available almost instantaneously to prevent automatic load shedding.
- Frequency control is the regulation of frequency of the electricity that utilities produce within a narrow band around 60 Hz (standard in the U.S.).
- Voltage regulation is the ability of a power source to maintain constant output voltage with changes in load.

PREPA designed its BESS to function primarily in the rapid reserve mode, preventing load shedding in its island network. The BESS experienced its first rapid discharge on November 23, 1994. A 410-MW unit of PREPA's South Coast Steam Plant was lost, resulting in a 21% system overload.
3 Lessons Learned

PREPA’s experience identified many pitfalls as well as optimum processes for planning, design, procurement, construction, operation, and maintenance of a large, integrated energy storage facility. This Lessons Learned document will be useful to the other utilities considering construction of similar facilities. The lessons learned are presented by project phase (see Figure 2) to indicate the type of challenges that can arise during each phase of a project.

Figure 2. Project Timeline and Key Milestones

3.1 Planning

This project was initiated in 1989, with internal planning documents prepared by the PREPA Planning Division with assistance from its architect/engineer, United Engineers & Constructors (UE&C). The utility evaluated alternative technologies, including batteries, flywheels, and gas turbines to combat frequency control issues that caused load shedding. PREPA was able to draw upon the experience of two large BESS facilities already in operation: Southern California Edison’s 10-MW/4-hour Chino facility operating since 1988 and Berliner Kraft und Licht’s (BEWAG) 17-MW/30-minute battery plant operating since 1987. PREPA determined that a BESS would provide the quickest response to power fluctuations and achieve the fastest payback. During the planning phase, the following lessons were learned:

- Establish a team to follow the project through completion.
- Identify up front who’s responsible for the system within the organization throughout all project phases.
- Determine project responsibilities for all participants before going to procurement.
- Coordinate meetings with licensing boards to facilitate the permitting process.
- Gather and evaluate as much performance data on other facilities as possible.
3.2 Design/Engineering

PREPA staff had considerable communications with UE&C, who directed the Design/Engineering phase. The utility wanted to make certain that the BESS was not a first-of-a-kind demonstration like the Chino and BEWAG plants. They insisted that all subsystems consist of commercially available components, however, very few components were in fact purchased off-the-shelf. In addition, PREPA did not want a turnkey project in which they would have minimal involvement; the utility wanted to be the system integrator. These two conditions significantly impacted the design/engineering phase. PREPA learned that the system integrator must:

- Select the architect/engineer with the most relevant experience.
- Be an active participant in system design.
- Accept that project phases are intertwined in large competitive solicitations (e.g., design phase overlapping procurement and construction phases).
- Verify available infrastructure before preparing an appropriate design (e.g., roads and the supply of electricity and water).
- Identify and design for site-specific environmental and climatic conditions.
- Design the building to facilitate regular maintenance and major overhauls.
- Consider the performance and cost implications of subsystem design and configuration.

3.3 Procurement

PREPA coordinated the procurement processes. Having a public power authority control procurement extended a complicated process, with seven sequential solicitations, into a two-year effort. In addition, PREPA had not built a major facility for 15 years. Nonetheless, PREPA staff undertook a number of initiatives that paved the way for construction:

- Dedicate a purchaser in the organization to ensure good communications and project continuity.
- Budget for cost variations (see Table 1).
- Insure that all potential bidders are invited.
- Design specifications that avoid multiple interpretations.
- Develop contingency plans for off-schedule equipment deliveries.

### Table 1. PREPA BESS Costs by Components (Million $)

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Principal Components</th>
<th>Proposed Bid</th>
<th>Ultimate Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Engineers &amp; Constructors</td>
<td>Design/Engineering</td>
<td>0.95</td>
<td>1.49</td>
</tr>
<tr>
<td>C&amp;D Charter Power</td>
<td>Batteries, Racks, Watering System</td>
<td>4.60</td>
<td>4.84</td>
</tr>
<tr>
<td>General Electric</td>
<td>PCS</td>
<td>5.40</td>
<td>5.40</td>
</tr>
<tr>
<td>Pauwels</td>
<td>Transformers &amp; 115 kV Interface</td>
<td>0.36</td>
<td>0.70</td>
</tr>
<tr>
<td>ABB</td>
<td>AC Switchgear</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>PACS Industries</td>
<td>DC Switchgear</td>
<td>0.50</td>
<td>0.72</td>
</tr>
<tr>
<td>Leeds &amp; Northrup/</td>
<td>Facility Control System &amp; Monitoring</td>
<td>0.80</td>
<td>1.33</td>
</tr>
<tr>
<td>Applied Control Systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aireko</td>
<td>Construction &amp; Balance of Plant</td>
<td>4.00</td>
<td>4.85</td>
</tr>
<tr>
<td>PREPA</td>
<td>Project Mgmt, Training, Testing</td>
<td>—</td>
<td>0.80</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>16.80</td>
<td>20.32</td>
</tr>
</tbody>
</table>

Lessons Learned from Puerto Rico BESS
3.4 Construction

PREPA worked closely with the general contractor who had ample experience in the construction of reinforced concrete buildings. However, the contractor's lack of experience with electric power installations prolonged the construction period even though PREPA Operations & Maintenance personnel were present throughout construction. The participation of key team members enabled several beneficial changes to building design during construction. Nonetheless, more proactive participation by the battery vendor and architect/engineer would have facilitated construction and acceptance testing.

- Bring all suppliers together to review system impacts of subsystem designs.
- Build time into the schedule for weather-related delays and construction errors.
- Insure that general contractors use qualified subcontractors for specialized work.

3.5 Initial Start-Up

After inauguration of the BESS in July 1994, PREPA experienced a frustrating shake-out period. The system failed frequently and it took months for the team to pinpoint all the causes of failure (such as corrosion on the gold-plated pins of the PCS). Likewise, domino effects further complicated the isolation of problems in component design and operation. PREPA staff were able to resolve these initial start-up problems due to their involvement in all phases of the project. The major lessons learned in this phase were:

- Verify control software for battery management (original charging algorithm did not result in full state-of-charge).
- Monitor all systems for unanticipated problems.
- Install appropriate ground detection equipment.
- Interface the BESS with central utility dispatch operations.
- Access design and construction staff as needed to resolve start-up issues.
- Allow for a long start-up period for one-of-a-kind projects.

3.6 Operations

Continuity in PREPA's BESS team facilitated the transition from initial start-up to full operations. One team member, who had been involved with the facility since the construction phase, continued as the plant manager through 1997. Unique problems in system operations were solved during the first two years of operation. PREPA staff made many modifications that improved BESS performance.
Areas of concern and lessons learned in this phase include:

- Coordinate smooth turnovers with all participants.
- Maintain trend data on BESS responsiveness.
- Improve operations by addressing engineering details.
- Choose upgradable, non-proprietary electronics and data systems.
- Implement fully debugged data tracking.
- Identify root cause of excessive cell failure

3.7 Maintenance

Battery cell failures and replacement have been the biggest maintenance issues. Building logistics aggravate this situation (rack design, no elevator to second floor, and limited heavy equipment handling capability). The smallest BESS outage possible to replace a few localized cells, is one-third of one floor (one string is comprised of three rows). Typically, an entire floor must be taken out of service, leaving only 10 MW available for load shedding avoidance. The time and effort required to change out cells is significant and costly. Three men can remove and replace a maximum of 16 cells in a day (Figure 4 shows one part of the effort). One of the biggest problems is rack design, which provides no clearance between the rack and the cell jars to permit the use of a forklift. The BESS battery technician designed a sling that was successfully used to remove good cells. A V-shaped forklift was also designed to permit removal of good cells from the bottom rack. The primary lessons learned here was to design the system for ease of maintenance:

- Acquire tools appropriate for maintenance.
- Install equipment to facilitate maintenance and safeguard personnel.
- Have realistic staffing expectations.
- Establish appropriate warranty conditions.

4 Conclusion

The BESS is working and contributing in a way no other generation asset can. The facility has successfully achieved its goal of providing rapid spinning reserve, frequency control, and/or voltage regulation. This was particularly the case in the aftermath of Hurricane Georges in 1998. Rapid discharge from the BESS continues to provide a reduction in network load shedding and in required system-wide spinning reserve that result in economic benefits for the utility. In frequency regulation mode, the BESS provides a fast response that reduces frequency deviations and provides operational flexibility during generation shortages. The BESS in voltage regulation mode helps sustain system voltage levels, especially during peak hours, by augmenting the reactive power load. PREPA is in the process of deciding how to proceed with cell replacements, and is determined to improve state-of-the-art BESS battery technology.
charge measurement and data acquisition flaws that hampered operations. The utility is now beginning the process of reviewing cell specifications for a second BESS facility located at the same substation near San Juan.

Despite the best efforts of those involved in the project, the PREPA BESS was still a first-of-a-kind system with its share of unanticipated problems. The lessons learned by this project should help future, large BESS projects achieve full operational status in a minimum amount of time.