Energy Storage/Distributed Resource Options At The University Of Maryland

Ndeye K. Fall, Mindi Farber De Anda[1]

Introduction

Commercial and industrial customers of electric power currently operate their own distributed generation and energy storage systems. These remote off-grid installations team generation and storage in a hybrid configuration. But grid-connected facilities typically are not in hybrid configurations. Why not? On the surface, the benefits of a grid-connected hybrid microturbine and energy storage system appear obvious; it enables the customer/operator to ride through periods of peak demand without incurring excessive costs. Are there other benefits? What happens when the building cooling, heating, and power (BCHP) system is also incorporated? What is really gained from the addition of energy storage? Which advanced battery technology fits best? When is it cost-effective to recharge the battery from a microturbine instead of off-peak electricity purchases? These are the questions this project sought to answer at the University of Maryland.

Chesapeake Building

The University of Maryland's Chesapeake Building houses the Cooling, Heating and Power (CHP) for the Buildings Integration Test Center. The Building Integration Test Center was designed to investigate how to integrate CHP systems into buildings and to integrate the equipment into BCHP systems. The Chesapeake Building is a 51,000 square-foot office building with four floors and approximately 200 occupants. It houses the university's accounting department, whose electricity usage plateaus during regular business hours. The Chesapeake Building is representative of medium-sized commercial buildings, which account for 23% of all buildings in the US. The Chesapeake Building currently has a 60-kW Capstone microturbine retrofitted for BCHP applications (see Figure 1). The BCHP systems operate from May to October.

Figure 1. Chesapeake Building with Capstone in Foreground

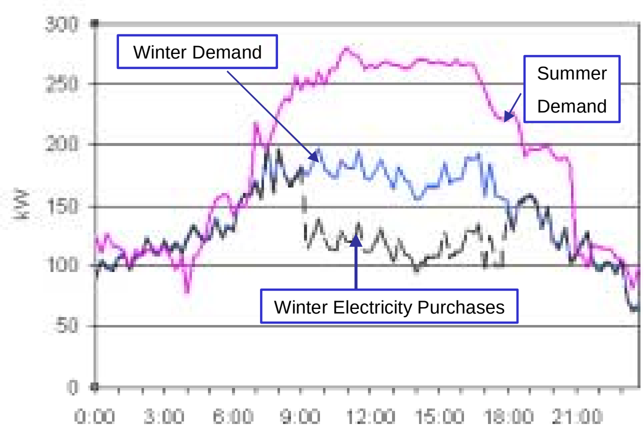

Figure 2. Chesapeake Building Load Profile

The Chesapeake Building's seasonal load profiles are shown in Figure 2. These load profiles are shown without BCHP, which reduces summer peak electricity demand by approximately 50 kW. The BCHP system became operational in late August 2001 before the Capstone microturbine was installed in January 2002. As a result, this graph displays:

- Summer 2001 electricity demand without microturbine or BCHP operation on a day with high load (top line)
- Winter 2002 electricity demand without microturbine or BCHP operation (middle

[1] Energetics, Washington, DC. Email: mfarber@energeticsinc.com

Sponsors: U.S. Department of Energy through Sandia National Laboratories with in-kind support from Oak Ridge National Laboratory and the University of Maryland

line)
- Winter 2002 electricity purchases, as reduced by the Capstone microturbine (bottom dashed line)

These load profiles show how an energy storage system could reduce energy costs, and thereby improve energy savings by:

- Shaving the load at utility-designated peak times and recharging at off-peak times
- Turning on when the electricity demand exceeds a set threshold (e.g., before 9am or after 5pm particularly in the Winter, to avoid high demand charges)
- Providing quality power protection when multiple motors turn on (there are no highly sensitive loads in the Chesapeake Building)

Distributed Energy Technology Simulator

The U.S. Department of Energy (DOE) is very interested in examining the net benefit of advanced battery technologies in hybrid configuration at the University of Maryland. With funding from DOE and the National Rural Electric Cooperative Association, Energetics has developed a simulator that can compare the technical and economic performance of up to five different distributed energy technologies. The simulator consists of two boxes: the power monitoring box on the right and the embedded controller on the left (see Figure 3). The power monitoring box is connected to current and potential transformers inside the Chesapeake Building's switchgear to measure current and voltage delivered to the building. These measurements are sent to simulator software in the embedded controller, which uses this information to mimic the operation of several distributed energy technologies. This data is then recorded and used to calculate the peak and off-peak energy demands that would result from the use of each technology. Economic data such as energy cost savings and peak demand charge savings are calculated to determine the net benefits of each technology.

Figure 3. Simulator Installed at the University

Energetics previously developed and validated a flooded lead-acid battery module at a co-op utility in North Carolina. The simulator had to be enhanced to include both valve-regulated lead-acid (VRLA) batteries and zinc bromine batteries, in order to compare their contribution to the Chesapeake Building. GNB provided the necessary information to create the VRLA module and ZBB assisted with the development and validation of the zinc bromine battery module. The modules in the simulator are not meant to be copies of proprietary designs; rather the operation is generalized in order to be indicative of a generic technology. A number of simplifying assumptions were used to enable data capture and analysis in 15-minute intervals:

- Flooded battery module operates at constant power discharge and recharge and stops discharging at 40% state of charge
- VRLA module operates at constant power discharge and recharge and stops its discharge at 20% state of charge
- Zinc bromine module operates at a constant power for a full discharge and recharges at a constant current

The zinc bromine battery simulation screen (see Figure 4) shows two sets of data. The monitored data includes voltage and current measurements from all three phases, as well as the power factor, temperature, real and reactive load of the building. The power factor is the ratio between the real power and the total power supplied. The real and reactive loads are calculated from the measured voltage and current.

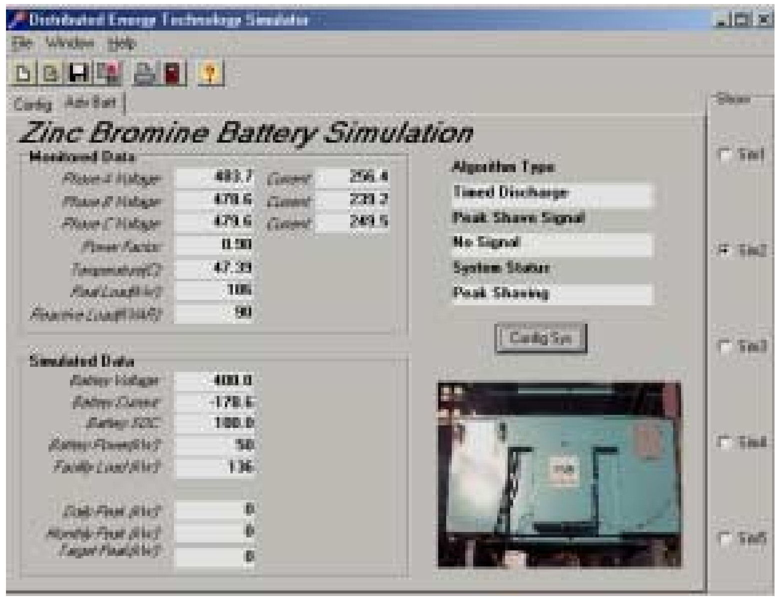

Figure 4. Zinc Bromine Battery Simulation Screen

The simulated data set includes the simulated load and virtual technologies' attributes such as current, voltage and state of charge for batteries. The simulated facility load is the real load minus the power provided by the simulated technology. The simulation also shows the daily and monthly peak of the facility load. The target peak is the maximum energy demand specified by the user during the peak-shaving time interval.

Simulation Parameters

Peak demand times and office operation hours served as the basis for sizing the batteries. Table 1 presents the electric rates that the University of Maryland has negotiated with its utility company, PEPCO, for all buildings on all campuses. These tariffs are very low, relative to demand charges and time-of-use rates charged elsewhere in the U.S.

Table 1. University Electric Rates

Rate	Time	Summer (Jun-Oct)	Winter (Nov-May)
On-peak electric (¢/kWh)	12pm-8pm	5.76	4.90
Intermediate electric (¢/kWh)	8am –12pm, 8pm-12am	5.09	4.34
Off-peak electric (¢/kWh)	12am-8am, weekend/holidays	3.5	3.06
Peak demand charges ($/kW)		15.00	4.00

The Chesapeake Building currently has a Summer peak demand that exceeds 250kW, a daily peak energy consumption of 1,000kWh and a daily off-peak energy consumption of 3,500kWh. The simulated battery technologies were sized at 50 kW/ 400 kWh to balance their capital costs with the savings they could generate. The simulator operated between 12pm and 5pm because the building load was at its peak during business hours (9am-5pm) and PEPCO charged peak electricity rates between 12pm and 8pm.

The batteries are virtually operated according to four algorithms that exist in the simulator software:

- Timed discharge -- the device is turned on and off at scheduled times each day, coinciding with the peak period
- Auto-bulk peaking -- a maximum peak energy demand is chosen, and the device is triggered to provide full power whenever the energy demand rises above this threshold
- Auto variable peaking -- a maximum peak energy demand is chosen, and the device turns on whenever energy demand rises above this threshold; however, the device provides just enough power to keep the energy demand below threshold

- Peak shave signal -- the device turns on when the facility receives a peak-shave signal from the utility, notifying its customer that peak demand rates are in effect

The timed discharged and auto-bulk peaking algorithms were used because they were the most appropriate for this Winter demonstration.[2] Three battery modules (flooded, VRLA and zinc bromine) operated under the timed-discharge algorithm from 12pm to 5pm. Two battery modules (VRLA and zinc bromine) also operated under the auto-bulk peaking algorithm with a threshold set at 150 kW. In hindsight, a different approach to shave electric spikes before the microturbine turns on and after it turns off, should have been included in the virtual operation period.

Simulation Results

Chesapeake Building's one-month demonstration was finished on March 4, 2002. The goal of this demonstration was to reduce the peak kWh purchases and demand charges as much as possible. Table 2 displays the peak and off-peak kWh purchases, for the Chesapeake Building, without the Capstone microturbine and BCHP operation and compares this to the reduced peak purchases with the batteries. The microturbine results were excluded because the meter at which the simulator was connected reported electricity demand for the building. The reduction in peak and off-peak demand will be calculated on the basis of the 60 kW output from the Capstone microturbine.

Table 2. Simulated Battery Technical Comparison, February 4 – March 4, 2002

Battery	Operating Algorithm	Displaced Peak kWh	Peak kWh Purchases	Off-peak kWh Purchases
No battery	NA	0	17,783	69,458
Flooded	Timed	5,250	12,533	75,772
VRLA	Timed	5,250	12,533	75,462
	Auto-bulk	4,275	13,508	74,693
Zinc bromine	Timed	5,250	12,533	74,288
	Auto-bulk	4,275	13,508	73,408

All batteries operated from 12pm to 5pm on weekdays. Those on a timed-discharge dispatch output the same peak energy. The zinc bromine and VRLA batteries operating under the auto-bulk peaking algorithm displaced the same amount of peak energy as they both were on when the load exceeded 150 kW. The difference in off-peak kWh purchases is explained by the variations in batteries recharge methods. The flooded battery module recharged to 105% state of charge, then trickled-charged up to 115% of its capacity. The VRLA battery module recharged to 100% and trickled-charged to 105% state of charge. The zinc bromine battery module was never overcharged, and as a result, required the least off-peak kWh purchases.

The economic comparison of batteries shown in Table 3 does not take into account the technologies' capital costs or operation and maintenance costs.[3] The zinc bromine battery seems to yield the greatest monthly savings, however, it costs twice as much as the other batteries. The batteries run on auto-bulk peaking show smaller demand charge savings because they reduced the highest peak to 173 kW, as opposed to 168 kW for the timed discharge batteries. Energy costs savings vary in accordance with the off-peak kWh purchases and energy displaced. The zinc bromine batteries, which are never overcharged, show the biggest savings. The batteries on timed discharge show better energy savings than those on auto-bulk because they displaced more energy.

Due to the university's low electric rates, the economics showed that the recharge from the microturbine not cost-effective in the winter. When operated in the Summer, demand charges of $15/kW result in a tripling of the monthly demand charge savings from any of the battery modules. Slightly higher Summer peak and off-peak energy charges at PEPCO make little change in monthly energy cost savings. Rather than ending the project at this juncture, it was decided to investigate the thresholds at which hybrid microturbine-BCHP –

[2] Peak shave signal can only work if the host site receives radio signals from the utility that alert it to peak demand periods. And auto variable peaking option works best in a season when peak demand can increase over time (more appropriate for Summer).

[3] This analysis was focused on monthly savings, not payback or net present value of overhaul, which are calculated from monthly savings, capital and O&M costs.

battery systems become economic. There are trade-offs among demand charges, peak and off-peak energy rates, and natural gas prices that could easily tip the scale in favor of the hybrid option.

Table 3. Simulated Battery Economic Comparison, February 4 – March 4, 2002

Battery	Operating Algorithm	Energy Cost Savings ($)	Demand Charge Savings ($)	Monthly Savings ($)
No battery	NA	0	0	0
Flooded	Timed	68	200	268
VRLA	Timed	77	200	277
	Auto-bulk	52	183	235
Zinc bromine	Timed	112	200	312
	Auto-bulk	91	183	274

While the analysis is not yet complete, time-of-use tariffs for commercial customers (general service less than 300 kW) offered by other utilities are being reviewed. For instance, if the project were located in Southern California, the economics would improve due to higher Winter demand charges and peak and off-peak energy rates of $5.40/kW, 13¢/kWh and 9.4¢/kWh, respectively[1]. In the Summer, significantly higher demand charges ($21.8/kW) and peak energy rates (21.3¢/kWh) and the same off-peak energy rate (9.4¢/kWh) would result in monthly energy savings double those found at the University of Maryland in the Summer, if the battery was recharged from off-peak electricity purchases. However, off-peak rates that high make recharge from the Capstone microturbine more appealing, especially if natural gas prices are low.

If the project were instead located in Northern Virginia, the Winter demand charge would be double at $8.23/kW, but the peak energy rate would be only 3.2¢/kWh and the off-peak energy rate would be substantially less at 0.5¢/kWh [2]. This combination of rates would result in Winter monthly energy savings double the value found at University of Maryland. With off-peak energy rates that low, battery recharge from the microturbine would never be an option. In the final report to be completed next month, other price combinations will be examined and thresholds identified.

References

[1] Southern California Edison Schedule TOU-GS-2, Option B, filed 12/23/97, last updated 3/28/02.

[2] Virginia Electric and Power Company Schedule GS-2T, filed 1/2/01.