

Sizing And Economic Analysis Of Energy Storage Devices

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Electric Energy Storage systems are beginning to move into commercial applications. New audiences are being introduced to the advantages of these technologies and they want to know how those advantages can be applied to their individual businesses. Information useful in a development or Government program settings does not fit in this situation. While cost benefit analysis and Real Levelized cost help us understand differences between viable technologies, they do not necessarily contribute to our understanding of a project application.

Presenting realistic forecasts of project benefits requires combining some technical operational detail for a specific device along with methods for transforming that performance to dollar and cents impact. The paper presents a comparative approach to that problem along with some results using real world data for technical performance and electric system tariffs and markets.

This method uses a technical model to simulate performance of energy storage application in a medium size commercial building. The results of this step are influenced by various inputs, including market prices, equipment size, efficiency and market strategy. Comparisons are made to evaluate appropriate applications for storage equipment based on different combinations of technology, market price and operating tariff.

A discounted cash flow methodology is used to make economic comparisons. This method provides a long-term look at the cash flow implications for a business using Internal Rate of Return (IRR) as a metric.

The storage system under study is assumed to generate savings by purchasing energy for recharge during off peak hours at wholesale power market prices and lowering metered consumption during peak hours by discharging.

DATA AVAILABILITY

Until recently the usefulness of this approach has been limited by the availability of consistent market price and technology data. For this study, 2001 market price data from the mid-Columbia Hub and the Pennsylvania, New Jersey and Maryland (PJM) grid operator are used. The mid-Columbia price data was provided internally by Bonneville Power Administration and show daily on peak and off-peak wholesale prices in \$ per MWH. PJM wholesale prices are represented by the hourly day-ahead data set published by PJM on their web site. These prices are set as the results of a day ahead bid process. 'Day of 'hourly prices are not currently available from PJM.

Three commercial tariffs are used in this study. The building, physically located in Portland, Oregon, is billed for electricity usage under Pacific Power and Light Schedule 48, large General Service – 1,000 kW and overⁱ. The tariff charges \$3.51 per KW of monthly demand and 3.1 cents per kWh used. Actual monthly bills for the building average about \$35,000 per month.

Retail prices in PJM are represented by Pennsylvania Power and Light (PP+L) tariff LP4, secondary voltage service for loads greater than 1000 kW.ⁱⁱ Pennsylvania tariffs are complicated by annual adjustments and transition charges. 2001 data was used in this study. This tariff charges \$6.225 per KW of monthly demand and 3.61 cents per kWh used on aggregate. Estimated annual charges for the study building are \$501,000 under the PP+L tariff.

The third representative tariff is Pacific Gas and Electric Company Schedule E20s Commercial /Industrial /General Service for customers with maximum demands of 1,000 Kilowatts or more.ⁱⁱⁱ

This tariff has winter and summer rates for super peak, shoulder and off-peak demand and energy. These rates were melded into summer and winter seasonal pricing for on peak and off peak periods. The melded rates are:

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summer energy (\$/kWh), \$0.14 on-peak, \$0.09501 off-peak; summer demand (\$/kW-Month), \$8.15 on-peak, \$2.55 off-peak, winter energy (\$/kWh), \$0.108 on-peak, \$0.0948 off-peak; winter demand (\$/kW-Month), \$3.65 on-peak, \$2.55 off-peak

Some good comparative data on performance and cost of specific storage technologies has been available for review in the past but was un-available for publication. Dr. John Boyes and his team presented “ Life Cycle Cost Analysis and Capital Cost-Benefit Comparison” to the ESA 2003 annual meeting in May 2003. This report presented a consistent set of efficiency, operations and maintenance costs, replacement frequency and capital cost for 8 energy storage technologies. The technologies covered are: Flooded Cell Lead Acid, Lead Acid VRLA, Ni/Cd, Regenesys, High Temp Na/s, CAES, Pumped Hydro and variable speed Pumped Hydro.

As a common reference, these data are very useful for future storage system analysis.

MODELING AND SIMULATION OF THE STORAGE SYSTEM

All electric energy storage systems share similar systems. These systems can be described by two major subsystems. First, the model must represent the interface between the storage technology and the electrical subsystem. Most storage technologies require DC to AC conversion. This is generally managed by an inverter or similar power control device using power electronics to connect power from the storage technology to the electrical subsystem synchronously and safely. The continuous electrical rating of the PCS is an important restriction on the ultimate performance of the system. Second, the model must represent the performance of the storage technology subsystem. This level of abstraction does not require second to second management of the technology.^{iv} The model will be required to respond as rapidly as market price signals are received. At the short end of ancillary service markets operated by various transmission operators operate on 5 to 15 minute intervals. Wholesale power markets operate on hourly schedules. This analysis plans on hourly interaction with the market at power levels provided by building metering.^v

At this time interval the only technical difference, for the purposes of this study, between energy storage systems in their round trip efficiency. As long as the real system can meet the charge rates implicit in the round trip efficiency for the time period modeled and the building load served, no other technical information is required. In this model, efficiency losses are divided equally between storage and discharge processes.

The system dynamics model used in this analysis describes these major subsystems in detail. The power conversion system (PCS) is comprised of the interconnection and conversion equipment necessary to interface a storage system with the electricity supply at a site purchasing electricity at retail. For a flow battery or Lead Acid battery application the PCS includes an inverter system for AC-DC-AC conversions and the necessary switch and isolation gear necessary for commercial building application.

Operational constraints are provided by a systems model developed specifically for the analysis of distributed resources. This model provides an hourly framework for examining the performance and control of electric energy storage. By adjusting the physical inputs, the model is capable of analyzing a variety of devices and situations. Major physical inputs treated as variables for this study include:

- Maximum and Minimum Energy Storage MWH
- On peak and off-peak KW demand target
- Power conversion system kW rating
- Storage device round trip efficiency %
- Hourly kW Building Load

From an engineering perspective, the model is based on straightforward energy accounting from the 1st law of thermodynamics; i.e. energy in equals energy out plus losses.

Integration of economic inputs and market strategy

The storage model is built in a commercial system dynamics environment. This environment provides a convenient programming system that allows integrated consistent treatment of economic and engineering data. Key economic variables used in this study include:

Maximum off peak purchase price in \$/mWh
On peak and off peak current market prices \$/mWh.

In addition, the 5 constraints discussed above also influence economic strategy since they sometimes prevent the system from taking advantage of potentially favorable market conditions.

In this model, electric tariff and wholesale market data combine with device physical considerations to identify savings potential in specific applications. This study uses tariff and market data from 2 geographic locations for comparison purposes. Also, opportunities under Pacific Gas and Electric tariffs in California are briefly addressed.

Storage system performance is measured by comparing the current operating cost for the building, based on tariff rates, with the total cost of operating the building with the storage system reshaping building loads to take advantage of available market opportunities. Savings are anticipated since the storage system lowers building load during high cost hours and raises load during less expensive hours. Because electric energy storage is “fueled” by electricity, total kWh consumption for the building always increases.

This is driven by the round trip conversion efficiency of the applied technology. Lower efficiency technologies will cause higher building consumption. Lower efficiencies also impact system costs and market strategies by restricting system performance at key times.

Two different comparisons are made in this analysis. For the PJM and Pacific Northwest cases, whole sale electric market price data was used to provide low cost off peak price input to the storage system. Benefits were provided by discharging during on peak hours and reducing the associated tariff demand and energy charges. Spread sheets were used to develop monthly “billing” calculations approximating monthly utility bills for the base case building load and for the building load as reshaped by the energy storage model. The difference between the before and after “billing” cases represents the annual dollar savings due to the operation of the energy storage system.^{vi}

The second approach used the Pacific Gas and Electric company tariff. This retail tariff is differentiated by season (winter and summer) and by on peak, off peak and shoulder periods. Each of these periods has specific demand and energy charges. These rates are high, but the price difference between the off peak and on peak hours may provide an opportunity to test a storage system operating on a single rate schedule. For this case, the base billing case represents the building load charge to the tariff, simplified as described earlier in this discussion. The second case reflects billing as shaped by the storage system. The difference is the savings due to storage system operation.

INTERNAL RATE OF RETURN COMPARISON

Each of the cases examined for this study have shown positive savings due to the operation of the storage system. These savings have been shown to be up to 20% of the annual cost of running the sample-building load. While promising, this does not let the potential investor know if the high cost of these units is a good investment.

Many options exist for this comparison. For this paper the Discounted cash flow method is applied. This method allows for realistic accounting for first cost and continuing operation and maintenance costs. This method is commonly used in large and medium companies in situations where project capital must be allocated among competing proposals. The Internal Rate of Return provides a standard comparison that allows objective project ranking.^{vii} It also has the advantage of reflecting the impact of taxes and depreciation on the viability of each project.

The DCF calculates the nominal cash impact of the project through each year of the projects life. 20 years is used in this analysis. The savings due to the storage unit is offset by O&M expenses, the cash outlay for the size and type of technology applied, and income taxes. The nominal annual net cash flow is the basis for the IRR calculation. The IRR is the discount rate that results in zero net present value at the first year of the project. Note that IRR can be negative or positive.^{viii}

Hurdle rates and tariffs

Industrial firms generally require capital investments to meet an IRR hurdle rate between 15% and 30%. As shown in Figure 1, none of the technologies analyzed here meet that rate.

The most promise was shown by the PG+E tariff. This is driven by the large on peak/off-peak price differential provided by this tariff. However insufficient market data is available to fully describe the opportunity.

Because the two other tariffs did not provide as large an on peak, off peak differential, their IRR results were much lower. Even the low demand charges associated with off peak purchases made at hourly prices per MWh for PJM and Pacific Power cases were insufficient to offset this advantage.

To properly reward energy storage systems, future tariffs need to offer seasonal and daily price signals. In addition, extension of existing cogeneration and distributed resource programs to include large systems would be helpful. In this study, companion tariffs offering special rates to storage and distributed generation devices were available. They were generally limited to 25kw or less in size making them unsuitable for commercial applications in larger buildings. However, larger customers always have the option of negotiating special tariff options. These opportunities for special retail test rates or tariff advantages should be encouraged by storage advocates.

Results discussion

This model allows testing of large and small systems in the context of real market and tariff conditions. Initial model runs were made using the Pacific Power tariff and varying the size of energy storage, the efficiency and the size of the power conversion system. System efficiency comparisons were limited to two cases, 65% and 75% for this study. Purchase price restrictions were varied also, but were found to overlap other variables. The base case investigation showed that storage amounts exceeding 24-30 MWh did not result in increased savings. The limiting factor turned out to be the available peak load during the week. The building load peaks during the 5 weekdays. The daily peak shaving energy requirement is about 28 MWh during the summer peak for 2001, the year used in this study... Smaller storage systems do not have adequate capacity to cut peak load later in heavy load weeks. Units smaller than 28 mWh cannot carry sufficient energy through a peak week. But, small units are more fully utilized during the rest of the year. Larger energy storage systems allow longer weekend recharge times, often using smaller cheaper PCS, that allow the storage system to be active throughout the entire week. Large systems cannot be fully charged during the 8-hour weekday off peak period. This methodology helps identify the magnitude of the economic and technical tradeoffs.

Smaller, less expensive energy storage systems worked well when coupled with smaller PCS systems as long as the building demand target was made large enough. 1-4 MWh systems coupled with 500kw PCS were sufficient to cut some peak loads during all 5-week days during heavy summer loads. This was in combination with a demand target of 1.75 MW. Gross savings were reduced, but IRR metrics were higher due to the drastically reduced system capital costs.

In smaller systems, higher efficiency technologies are able to last longer during higher load weeks more frequently than lower efficiency systems. Because the model assumes 1/2 of the losses will be assigned to the discharge process, a higher efficiency system will operate longer at full output. Since the model will not recharge larger storage systems till the next off peak period, this is an interesting impact. Like wise high efficiency will allow full recharge quicker with limited PCS capacity. During mid week 8 hour off peak recharge windows, high efficiency systems reached full recharge over a wider range of operating conditions.

Results

28 model runs were made for this study. Positive annual savings were reported for all runs. PCS capacities were varied between 500 kW and 2mW. Maximum mWh storage was varied from 1 mWh to 30 mWh. On Peak and off-peak demand limits were varied between 1 mW and 2 mW. Small systems with storage of 4 mWh or less were identified as having the best opportunity for positive IRR values even though larger systems produced larger annual savings. Large systems often showed twice the annual savings of small systems. 4 mWh and a 8 hour discharge period along with a 1.5 mW on peak billing demand target, was adequate to reduce the building peak load for most of the business week during the heaviest summer load period. Large savings also occurred during the remainder of the year when modest demand cuts resulted in reduced peak demand

charges. Note that the PJM and Pacific Tariffs charged for demand based on the peak value for the month. If the storage system runs out of energy during only 1 peak hour during the billing month, demand charges are not reduced for that month.

To summarize results, the IRR model was used to plot IRR vs. Annual Savings lines, for the technologies listed by John Boyes, based on standard .5mW, 4 mWh systems. A general curve for Ni/Cd systems was not included in this study. The expensive replacement cycle for this system was not compatible with the IRR model. The Ni/Cd cash flow produced unstable IRR results.

Results from 4 specific model^{ix} runs were then plotted as 16 individual points. For comparison purposes, Ni/Cd and Regenesys systems were grouped at 65% efficiency and the remaining systems were analyzed as 75% efficiency. The actual efficiency of the remaining systems ranged from 70% to 78%. These model runs represent specific model savings and IRR outcomes for each technology. The resulting figure 1 shows how the current dollar benefits of storage technology compare to each other and to IRR hurdle rates. This is a useful comparison for examining the potential for energy storage applications in commercial buildings.

Results are shown in Figure 1 and the model run data is shown in Figure 2

Study results based using the PG+E tariff were promising but inconclusive. The tariff specifications for start and duration of the daily billing periods do not conform to wholesale standards and as such are not a perfect fit for the model. However, accounting for the actual dispatch of the model over time the results should be accurate in future comparisons with the other two tariff cases. The winter summer change can be accommodated directly. The major issue was the lack of comparable California wholesale market prices. Testing of the model using the on peak, off-peak tariff differential did not show savings. Several model runs were made using scaled up mid-Columbia price data. The results were promising but are not realistic due to the price and availability uncertainties involved in moving firm power from Pacific Northwest markets to California.

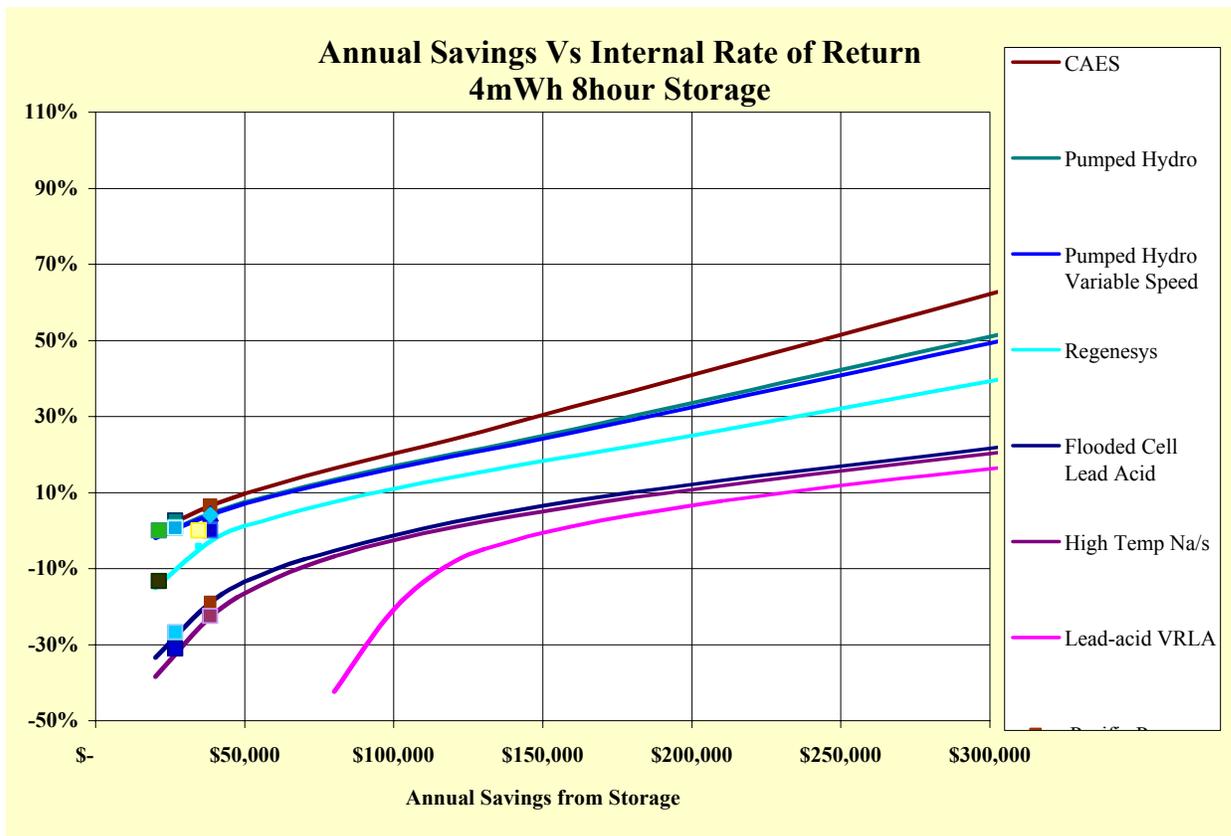


Figure 1

75% Efficiency	Technology					
	Flooded Cell Lead Acid	Lead-acid VRLA	High Temp Na/s	CAES	Pumped Hydro	Pumped Hydro Variable Speed
Pacific Power						
Annual Savings	\$38,486	\$38,486	\$38,486	\$38,486	\$38,486	\$38,486
IRR	-18.9%	0>>	-22.5%	6.5%	4.4%	4.1%
PJM Annual Savings	\$26,798	\$26,798	\$26,798	\$26,798	\$26,798	\$26,798
IRR	-26.7%	-75.1%	-31.1%	3%	1%	1%
65% Efficiency	Ni/Cd	Regenesys				
Pacific Power Tariff Annual Savings	\$34,520	\$34,520				
IRR	0>>	-4.2%				
	Ni/Cd	Regenesys				
PJM Annual Savings	\$21,196	\$21,196				
IRR	0>>	-13%				

Figure 2 Modeled Data Points input to figure 1

REFERENCES

ⁱ http://www.pacificpower.net/Regulatory_Rule_Schedule/Regulatory_Rule_Schedule2127.pdf

ⁱⁱ http://www.pplweb.com/delivering_energy/a/reference/regulated/tariff/ratelp4.pdf

ⁱⁱⁱ http://www.pge.com/customer_services/business/tariffs/pdf/E-20.pdf

^{iv} This discussion does not refer to very fast reacting storage systems connected synchronously to medium and high voltage system (e.g. SMES) used for real time voltage support and provision of reactive power. This discussion applies to real power delivery only and also assumes transparent interconnection with a building distribution system.

^v Thanks to Phil Choma and Alan Crymes of BPA for their assistance with building data.

^{vi} While this comparison is realistic it has not been verified by comparison with an operating physical storage system in a real building.

^{vii} IRR calculations also depend on assumptions of inflation and future prices for electricity. In addition, this analysis forecasts that the storage system will reshape the load of the building in the same way each year of the forecast. This is not realistic. Running the model for each future year would solve this problem if exogenous price forecasts were used. Such forecasts are not readily available at this time. Other limitations also exist. See, among others “Techniques of Financial Analysis; Ninth Edition by Erich A. Helfert for additional information.

^{viii} IRR assumptions are: 20 year project life, 34% income tax rate, 5 year depreciation life, GDP deflator through 2011 from California Energy Commission, 2.5 % through remainder of 20 year period

^{ix} These runs used a 4 MWh storage capacity, 0.5Mw PCS, \$40/Mwh off peak purchase price cap and 1.5 mw demand caps for on and off peak periods. They compared performance for Pacific Power and PPL tariffs.