Benefit and Cost Comparisons of Energy Storage Technologies for Three Emerging Value Propositions[1]

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Abstract
This paper reports the methodology for calculation and some initial results of a benefit-cost evaluation of modular energy storage used by the utility to augment subtransmission and/or distribution (T&D) systems and utility customers to reduce utility bills and/or to reduce loses due to power problems.

Introduction

This work brings together efforts which were previously carried out separately under the US Department of Energy (DOE) Energy Storage Systems (ESS) program. The primary objective is to express electricity storage benefits and costs – often calculated using different bases – using consistent assumptions, so that more helpful benefit/cost comparisons can be made. In addition to developing a methodology, this work has defined an initial set of value propositions for energy storage systems used as distributed energy resources (DERs). The framework is being exercised using benefits identified in previous work by Distributed Utility Associates sponsored by the US DOE ESS program [1] and the California Energy Commission [2], and costs based on previous work by Longitude 122 West and Advanced Energy Analysis for the US DOE ESS program [3], [4]. This work is a follow-up to a previous attempt to make such comparisons. [5]

Scenarios and Assumptions

Three value propositions are presented to illustrate the process. These are considered to be some of more financially attractive and technically viable ways that modular energy storage could be used more widely.

- Utility owned transportable storage – the case evaluated involves use of a storage system in alternating years for: 1) utility electricity distribution equipment upgrade deferral and 2) improved localized reliability and/or power quality or for temporary power (e.g. at construction sites);
- A storage system used for 1) T&D upgrade deferral for one year and 2) wholesale electricity price arbitrage (buy low – sell high) thereafter;
- Energy end-user owned storage used to serve on-site electricity needs during periods when on-peak and "critical peak" pricing prevail.

The assumed operating and design parameters for the three scenarios are listed in Table 1.

Table 1. Parameters of Value Proposition Scenarios for Energy Storage Benefit / Cost Analysis

	Scenario 1:Modular T&D Deferral with PQ	Scenario 2: T&D Deferral with Arbitrage	Scenario 3: Customer Bill Optimization
Description	1st year deferral, 2nd yr PQ/reliability; move to new location; 3rd year deferral, 4th year PQ, etc.	1 year deferral, subsequent years arbitrage	Operate during peak and critical peak hours to avoid time-of-day charges and earn discount
Power range	300 kW – 1 MW	500 kW – 2 MW	20 kW – 1 MW
Hours of dispatchable storage	4 - 5 hrs	4 – 5 hrs	5
Energy stored, kWh	1.2 – 5 MWh	2 – 10 MWh	100 kWh – 5 MWh
Hours or days of operation per year	T&D: 200 hrs/yr PQ: 20 hrs/yr	T&D: 200 hrs/yr Arbitrage: 1000 hrs/yr	Critical peak: 60 hrs/yr Total peak: 1600 hrs/yr
Technology issues	Must be portable, suitable for infrequent use, rapid availability	Routine use, high duty cycle	Routine use, high duty cycle

[1] Funded in part by the Energy Storage Systems Program of the U.S. Department Of Energy (DOE/ESS) through Sandia National Laboratories (SNL)

Benefits and costs are calculated using common financial bases and assume a ten-year life. The economic assumptions are shown in Table 2.

Table 2. Economic Parameters for Life Cycle Benefit and Cost Analysis

Parameter	Value
General inflation rate	2%
Discount rate	10%
Service life	10 years
Utility Fixed Charge Rate	11%
Customer Fixed Charge Rate	15%
Fuel cost, natural gas (for surface CAES only)	5 $/MBTU
Electricity cost, charging	10 ¢/kWh

DER technologies include various existing battery types and several other technologies with potential to match the energy and power characteristics required for these cases. These are listed in Table 3.

Table 3. Technologies Considered for each Scenario

	Scenario 1: Modular T&D Deferral with PQ	Scenario 2: T&D Deferral with Arbitrage	Scenario 3: Customer Bill Optimization
Technologies that qualify	Lead-acid batteries, conventional and VRLA Ni/Cd batteries Li-ion batteries Zn/Br batteries V-redox batteries High-speed and low-speed flywheels Low-speed flywheels Lead-carbon asymmetric capacitors Hydrogen fuel cell	Lead-acid batteries, conventional and VRLA Na/S battery Ni/Cd batteries Li-ion batteries Zn/Br batteries V-redox batteries High-speed and low-speed flywheels Lead-carbon asymmetric capacitors Surface CAES Hydrogen fuel cell	Lead-acid batteries, conventional and VRLA Ni/Cd batteries Li-ion batteries Zn/Br batteries V-redox batteries High-speed and low-speed flywheels Lead-carbon asymmetric capacitors Surface CAES Hydrogen fuel cell

<u>Scenario 1: Transportable Storage</u>

The operational characteristics for Scenario 1 are used to illustrate the methodology for combining benefits and costs. In Figure 1 below, the operating hours are shown for a modular, transportable unit that is used in odd years for T&D deferral, and then moved to be used in even years for power quality or reliability applications. A 5-hr energy storage system is assumed. In Figure 2, the current year resultant benefits are presented, (derived from previous studies [6]), in current dollars with 2% inflation. These benefits represent a mid-point of estimated values for this application. The current year costs for owning and operating a lead-acid battery system to perform these operations are shown in Figure 3. The cost values include capital carrying charge, electricity, O&M, and replacement costs, and are taken from a previous study [3].

In the original study, the replacement period for the energy storage component of the system was assumed to be six years, and a complete cell replacement was assumed. In this current scenario, however, the system is cycled infrequently. If proportionally less replacement cost is required, then an overall lower system cost is possible. Thus, in Figure 4, the present value of benefits and costs are shown again, including a case that assumes a reduction in replacement costs due to infrequent use and/or limited discharge depth. For the scenario evaluated, using a discount rate of 10%, the cumulative present value of benefits over 10 years is 1203$/kW. The cumulative present value of costs based on original cost assumptions is 1619$/kW, and the cumulative present value of costs for a system with reduced replacement costs is 1200$/kW. Thus, if replacement costs can be reduced, it is possible to approach a benefit / cost ratio greater than one.

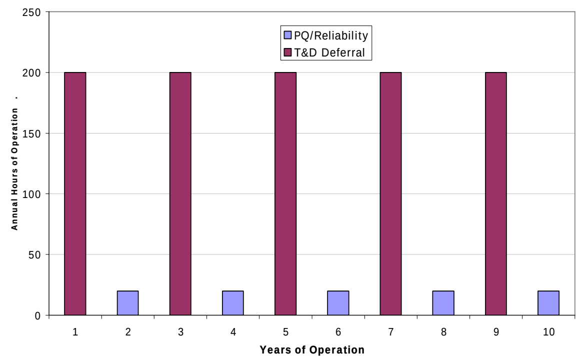

Figure 1. Scenario 1 Hours of Operation per year: T&D Deferral with Power Quality

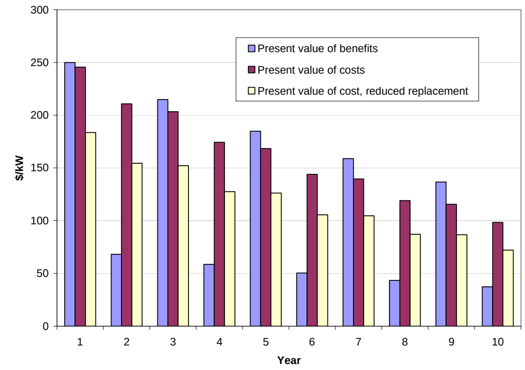

Figure 4. Present Value of Benefits and Costs ($/kW) for Battery system in Scenario 1 comparing original costs to reduced replacement costs.

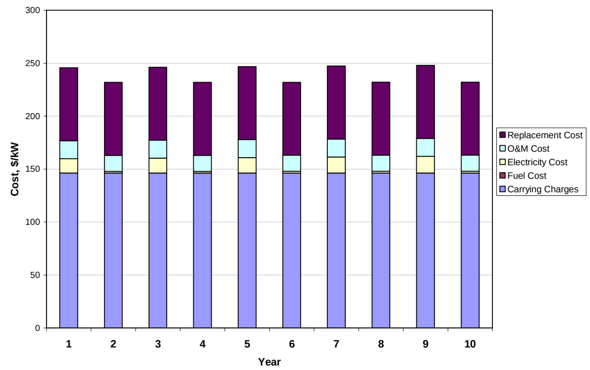

Figure 3. Costs of Lead-Acid Battery System ($/kW) for Scenario 1, based on original costs

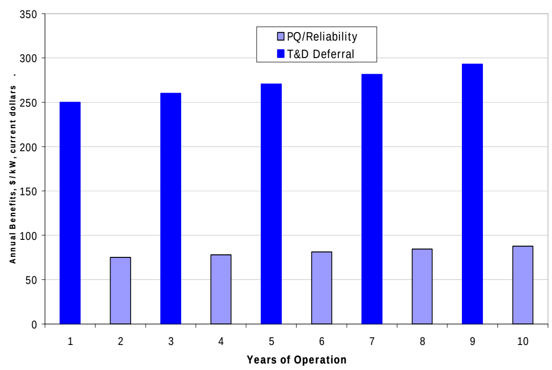

Figure 2. Scenario 1 Benefits ($/kW): T&D Deferral with Power Quality

Other technologies have also been given a preliminary screening. Based on costs from the previous study, but adjusting the replacement cost to account for reduced cycling, the present values of benefits and costs over 10 years are shown in Figure 5. Since the lead-acid battery has the lowest cost, it has the best benefit/cost ratio.

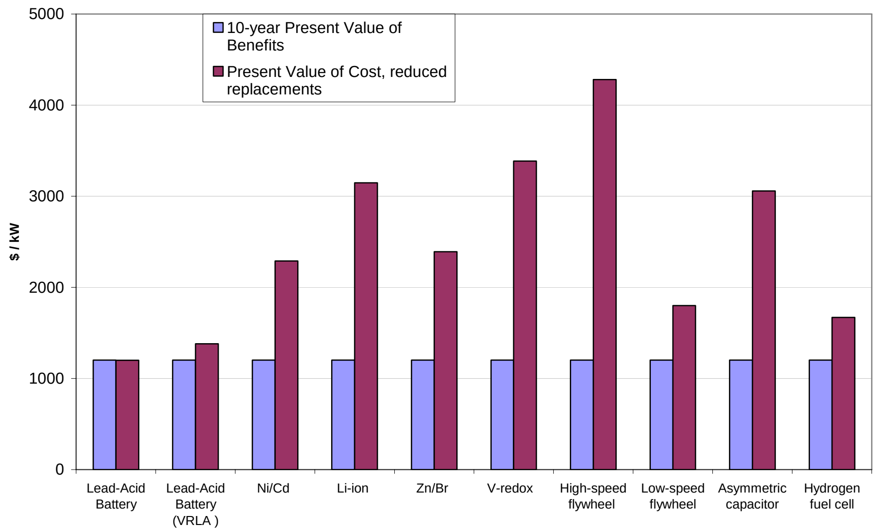

Figure 5. Present Value of Benefits and Costs over 10 years for technologies in Scenario 1.

Scenario 2: T&D Plus Arbitrage

For this scenario, an energy storage system is deployed to defer a T&D upgrade for one year. A 5-hr system is assumed. A large benefit results in the first year, in which the system is operated for 200 hours. The value of $650/kW represents the upper end of benefits estimated for this benefit [2]. After the first year, the system is used for arbitrage. It does not have to be transported to another site. The arbitrage scenario evaluated assumes 1000 hours of operation per year. (The number of buy low - sell high transactions is heavily dependent upon the fully burdened cost of O&M per kWh discharged for the storage unit, including a sinking fund for cell replacement. The assumed value of 1,000 hours reflects a fully burdened O&M of about 1¢ to 2¢/kWh_{out}.)

Electric energy price arbitrage exploits wholesale electricity price volatility and diurnal variability. Benefits accrue when storage is charged using low priced off peak energy, for sale when energy price is high. Storage losses or inefficiencies add to the effective charging cost. Charging cost and the *fully burdened* O&M cost are compared to the prospective sell opportunity to determine whether the transaction is profitable. So "profit" is calculated as follows:

Profit = Sell Price - (Charging Energy Price ÷ Storage Efficiency) - O&M.

For this study, the calculation of profit (net benefit) was accomplished using a simple model – developed by DUA – that uses "perfect knowledge" about future prices to "look ahead" at future energy prices, to identify profitable sell opportunities. The dataset – comprised of 8,760 hourly price points – is an electric energy price projection for California that was created by a "production cost model."

Values of net arbitrage benefits in Figure 5 reflect profit for storage operated for one year. Storage systems evaluated have fully burdened variable O&M of a) nothing, b) 1¢/kWh, and c) 2¢/kWh. The spread shown for each plot reflects profit for storage efficiencies ranging from 70% to 90% and for storage whose discharge duration ranges from one hour to eight hours.

A representative set of results (present value of benefits and costs) for Scenario 2 for the same lead-acid battery system considered previously are shown in Figure 6. Unlike Scenarios 1 and 3, in this scenario, the benefit is a net benefit, since the variable O&M and charging electricity costs are already included in the arbitrage dispatch model. Therefore, in this case, the costs are only those for capital carrying charge and fixed O&M. To give the most optimistic projections, the results in Figure 6 assume no replacements. The cumulative present values over 10 years for benefits and costs are 775 $/kW and 1090 $/kW, respectively. Most of the benefit comes from the T&D deferral and very little from arbitrage.

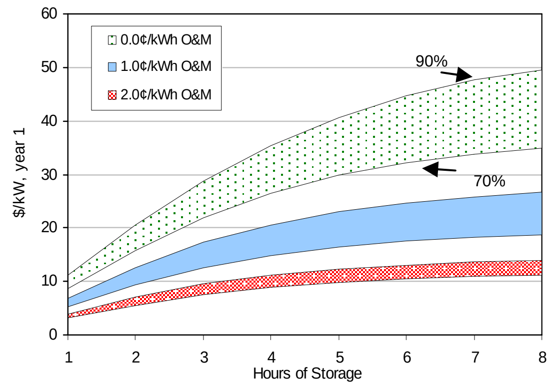

Figure 6. Net Arbitrage Benefits for Scenario 2

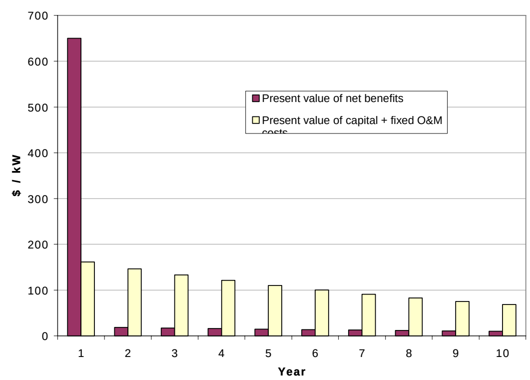

Figure 7. Present Value of Benefits and Cost for a Lead-Acid Battery system in Scenario 2

<u>Scenario 3: Peak and Critical Peak Pricing</u>

In this scenario, a commercial end-user's utility bill is minimized by the use of storage during peak and critical peak times. Pacific Gas and Electric Company (PG&E) is offering Critical Peak Pricing (CPP) to some customers. In this situation, a customer is offered a discount on electricity prices during "non-critical" times (e.g. when generation reserve margins are adequate). This offer is made if the customer agrees to pay "very high" prices during critical peak periods in return for the discount. These prices can be as high as 5 times the normal peak energy charge, and be expected to prevail several times per year (PG&E target is 12 times/yr), for periods lasting from 3 to 6 hours per event. Thus, a customer might make such an agreement using energy storage.

Critical peak and peak pricing benefits were calculated based on PG&E E19 Medium Commercial Rates [7]. The annual benefit due to CPP provisions for operation of 12 full 5-hr discharges per year (60 hrs) is estimated as $25/kW per year. The annual benefit for operating storage during all peak-period price hours – including demand charge reduction – is $100/kW-year. An operating scenario of 1,600 hours per year is assumed. These values have been used to calculate benefits for Scenario 3.

In Scenario 3, a 5-hour energy storage system is installed and operated both during critical peak price hours *and* to reduce energy use during times when normal peak energy prices prevail. Current dollar benefit values with 2% inflation are shown in Figure 8 for each of 10 years. Preliminary results (present value of benefits and costs) for a lead-acid battery system operating in Scenario 3 are shown in Figure 9, for each of 10 years. Even using a reduced replacement cost, the benefits are insufficient to break even.

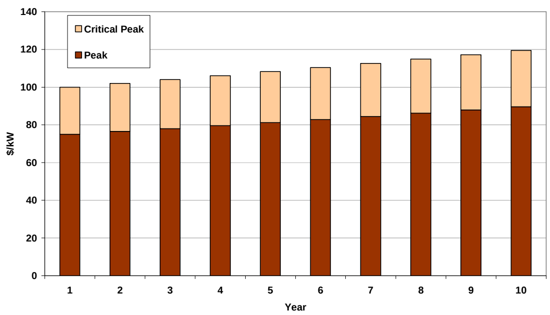

Figure 8. Peak and Critical Peak Benefits

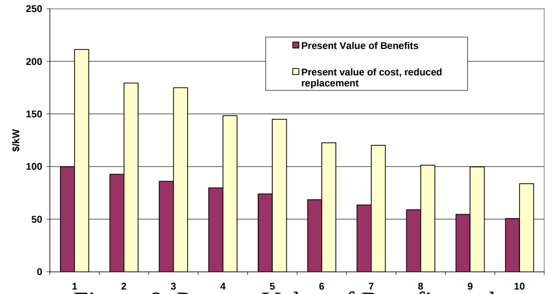

Figure 9. Present Value of Benefits and Costs for Lead-Acid Battery in Scenario 3.

Conclusions and Plans

This work has focused on developing a framework with consistent assumptions (especially financial bases) for estimating benefits and costs. In the near term, energy storage – especially modular, distributed storage – has its best prospects as a localized "capacity resource;" used to defer T&D upgrades or to augment the T&D system (e.g. for increased reliability and/or improved power quality). Depending on operational compatibility, storage used for such localized capacity-related needs can also provide regional benefits to the grid including reduced demand for generation and transmission capacity. Furthermore, the need to aggregate numerous individual, often year-specific benefits to cover storage's "high" lifecycle costs makes transportability quite attractive.

The initial results for the arbitrage case suggests that energy storage system fully burdened costs must be reduced if modular, distributed storage will generate profit from wholesale energy price arbitrage. The challenge is that, even for regions with "high" energy prices, during most hours in the year wholesale energy prices are determined by large power plants with low marginal cost. Those prices are just too low for profitable arbitraging.

The 10-year benefits and costs for the lead-acid battery in Scenarios 1, 2, and 3 are shown in Figure 10. These results are preliminary and meant to be representative of the process of structuring the analysis. In continuing this work, we will focus on refining the analysis, especially of Scenarios 2 and 3, and addressing the additional technologies.

Development of the framework also coincides with the need to revisit existing, increasingly outdated energy storage cost estimates, so as to reflect recent cost reductions, especially those related to storage media and inverter upfront cost.

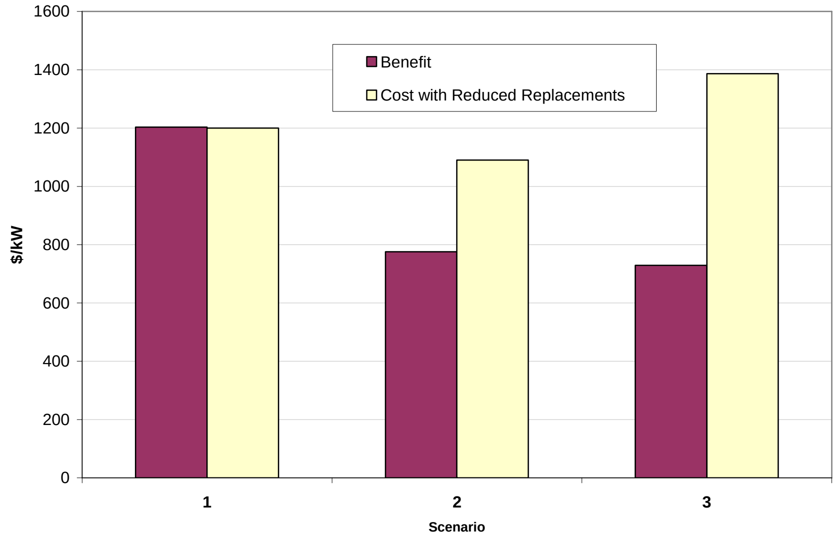

Figure 10. 10-year Present Value of Benefits and Costs for a Lead-Acid Battery System in Scenarios 1, 2 and 3.

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