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DYNASTORE Operating Cost Analysis of Energy Storage for a Midwest Utility

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ABSTRACT

The objective of this project was to determine the savings in utility operating costs that could be obtained by installing a Battery Energy Storage System (BESS). The target utility was Kansas City Power and Light (KCPL), a typical midwestern utility with a mix of generating plants and many interconnections. The following applications of battery energy storage were modeled using an Electric Power Research Institute (EPRI) developed and supported program called DYNASTORE:

1) Spinning Reserve Only
2) Load Leveling with Spinning Reserve
3) Load Leveling Only
4) Frequency Control

DYNASTORE commits energy storage units along with generating units and calculates operating costs with and without energy storage, so that savings can be estimated. Typical weeks of hourly load data are used to make up a yearly load profile. For this study, the BESS power ranged from "small" to 300 MW (greater than the spinning reserve requirement). BESS storage time ranged from 1 to 8 hours duration (to cover the time-width of most peaks). Savings in operating costs were calculated for each of many sizes of MW capacity and duration. Graphs were plotted to enable the reader to readily see what size of BESS affords the greatest savings in operating costs.

INTRODUCTION

As the cost of electrical energy continues to increase, and the public becomes more aware of the need for conservation of energy resources, the benefits of energy storage have become more significant now than they were in times past. Some of these benefits from energy storage are:

- Increased reliability of the electrical generation, transmission, and distribution system,
- A ready supply of emergency electrical power/energy,
- Deferral of new construction of generating plants, transmission lines, and substations.

This project is an important part of a larger effort to quantitatively determine the economic benefits of energy storage. In particular, we are studying the benefits of Battery Energy Storage Systems (BESSs). Specifically, we are investigating and evaluating methods for calculating dollar savings in electric utility operating costs that can be realized from a BESS that is properly "sized" for that utility. To date, we have done this study for an island utility with no interconnections, and for a typical midwestern U.S. utility that is strongly interconnected with its neighbors. It is on the latter project that this paper reports.

A brief review of the literature is presented here. First, an overview of the current technology and a review of the existing BESSs in operation are presented in [1]. This includes a spreadsheet program that provides a way of tabulating costs and savings over the 20 year expected life of a BESS. Additional overview information is presented in [2], along with milestones that have been achieved recently.

Improvements to various spreadsheet models were made in [3,4] in an attempt to more comprehensively account for all the costs incurred and to incorporate the use of proper accounting procedures. Comparisons with existing BESSs were made to verify the accuracy of the new spreadsheet models with respect to costs and benefits. Actual costs reported by the Crescent Cooperative [5] were used by Wiles [4] in his spreadsheet model, with accurate results.

Battery sizing studies for Pacific Gas and Electric (PG&E) and the Puerto Rico Electric Power Authority (PREPA) were done by the authors and graduate student Scott Deffenderfer. Building layouts were done by graduate student Jeremy Scott. The results were presented in Sandia Reports [6,7,8].

Engineering design considerations and the design and costs of the 10 MW Chino plant of So. Calif. Edison were reported in [9, 10]. The costs and benefits of BESS applied to an "island" utility were presented in

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[11, 12]. The DYNASTORE User's Manual is included [13].

MODELING OF THE SYSTEM WITH DYNASTORE

The plan for this study was to model the target utility system, KCPL, using DYNASTORE, a software program that provides unit commitment of energy storage units in an economic manner along with other generating units [13]. It then calculates operating costs with and without energy storage to give the user a "dollar" number for the savings in operating costs afforded by the energy storage facility.

A list of data needed to perform the study and run DYNASTORE was prepared and forwarded to the target utility. After the data requested was provided to the UM-Rolla team, it was entered into the many data entry forms required by DYNASTORE. The data was corrected until it passed all the DYNASTORE tests, then the baseline costs were checked for reasonableness with the help of the target utility and by comparison with actual utility operating cost data. The tasks required to complete this effort are given below:

1) Provide a detailed listing to the utility of the data items needed to perform the study.
2) Collect the data from the target utility.
3) Enter data into the data entry forms of DYNASTORE.
4) Check data input for errors, recheck, and check again.
5) Check calculated results for reasonableness with the target utility, and compare results with actual utility operating data.
6) Define the BESS applications, and size the BESS for each.
7) Run DYNASTORE for each case and document the results.

Step 5) is not a simple task because DYNASTORE does not include fixed cost data in its calculations. DYNASTORE calculates operating costs with and without energy storage, but fixed costs would be the same for both cases. Since fixed costs would subtract out in calculating savings, they are never entered; i.e., there is no place on the input data form for fixed costs. However, DYNASTORE calculated costs cannot be compared with actual utility costs without including fixed costs. This problem was solved by adding a spreadsheet in which fixed costs were added to the calculated costs. With this addition, the target utility was able to compare our calculated costs with their actual costs for a base case that did not include energy storage.

At the end of Step 5), KCPL staff agreed that the costs calculated by DYNASTORE were "close enough" to their actual costs for our model to be an "acceptable/valid" cost model. The excellent co-operation and support in supplying the large quantity of data in sufficient detail for accurate modeling of their system using the EPRI DYNASTORE program was critical to the success of this work.

BATTERY ENERGY STORAGE APPLICATIONS AND DEFINITIONS

In order to conduct the study, a range of BESS "sizes" had to be defined:

- BESS power was varied from 40 MW to 300 MW.
- BESS storage time was varied from 1 hour to 8 hour.
- Spinning reserve requirement was 6%.

Selected BESS applications were:

1) Spinning Reserve Only,
2) Load Leveling with Spinning Reserve,
3) Load Leveling Only,
4) Frequency Control.

The range of MW sizes was chosen for the following reasons: The spinning reserve requirement was 6% , which corresponds to 176.8 MW for a peak of 2947 MW. By extending the BESS power to 300 MW, we should be able to see the spinning reserve savings saturate, while the load leveling application continues to increase in potential savings.

The range of storage times was chosen for the following reasons: Because of the utility's load profile, which in general has broad peaks of more than 4-hours duration, a BESS of duration out to 8 hours was chosen to determine how much savings could be obtained, if any. This would allow the BESS to be committed to shaving broader peaks.

NOTE: The savings calculated in this study are savings in utility operating costs with the BESS committed to operation, as opposed to operation without the BESS. The capital costs of the BESS are not included.

RESULTS: SAVINGS IN OPERATING COSTS OBTAINED FROM DYNASTORE

For each of the BESS operating modes listed below, savings in operating costs afforded by BESS as calculated by DYNASTORE are shown first as tables of cost savings numbers followed by graphs for the following cases:

Spinning Reserve Only
Load Leveling with Spinning Reserve
Load Leveling Only
Frequency Control

Spinning Reserve Only

For a BESS dispatched as Spinning Reserve Only, the duration of the batteries in terms of hours of service on-line does not vary the $ savings because the batteries are never discharged in the reserve mode. It is sufficient to say that the BESS will supply the electric utility "long enough" to outlive the outage, or enable backup generation to be started and brought on-line. It is assumed in this study that a BESS of 1-hour duration is sufficient for Spinning Reserve. For this reason, the graphs show straight lines of constant savings from 1-hour duration out to 8-hours for each of the BESS sizes. This is consistent with the situation where another utility specified that a BESS deliver a certain MW power for 15 minutes with a ramp-down to 0 over the next 15 minutes.

As the power of the BESS increased, the savings also increased until the 6% spinning reserve requirement of nearly 180 MW was reached. Increasing the BESS power above 200 MW does not produce additional savings. In fact, the savings decrease slightly as the capacity of the BESS is increased from 200 to 300 MW. To facilitate the study, the upper limit of the BESS power was set at 300 MW to allow us to get past the spinning reserve requirement and determine the savings afforded by other BESS operating modes.

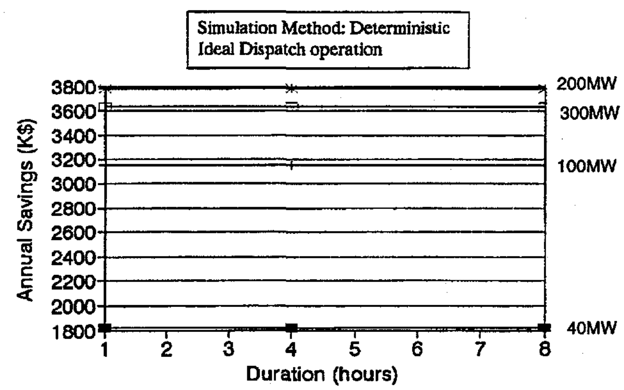
A summary of the annual savings ($K) in operating costs for a BESS used for Spinning Reserve Only is shown in Table 1. The straight line graphs for 1995 are shown in Figure 1.

Table 1. Summary of Annual savings ($K) When BESS is Used for Spinning Reserve Only

1995 Ideal Dispatch
Simulation Method: Deterministic

BESS Size (MW)	1 - hour	4-hour	8-hour
40	1,826	1,826	1,826
100	3,156	3,156	3,156
200	3,781	3,781	3,781
300	3,637	3,637	3,637

Figure 1. BESS used for Spinning Reserve Only (Year: 1995)



Load Leveling with Spinning Reserve

One feature of the DYNASTORE program in this mode is to allocate any portion of the BESS resources not needed for load leveling to spinning reserve. This enables the electrical system to take better advantage of the resources offered by the BESS in some applications. This feature also provides the user with a check on the DYNASTORE computations. In general, the savings afforded by the Load Leveling and Spinning Reserve modes considered separately, add up to be "reasonably" close to the savings afforded by Load Leveling with Spinning Reserve. The differences are explained below.

DYNASTORE calculations of savings for Spinning Reserve Only do include start-up costs, min. up/down time costs, and other stop/start costs, but do not include the incremental cost calculations (lamda) to follow the load variations with time. Conversely, the Load Leveling Only calculations include incremental costs to cover load variation, but do not include start-up costs. Hence, savings for Spinning Reserve Only plus savings for Load Leveling Only do not add up exactly to the savings for Load Leveling with Spinning Reserve. Another factor is that the BESS may not be committed by DYNASTORE unless it has the storage time to shave the peak load at that time; whereas, this is not a necessary consideration for spinning reserve commitment.

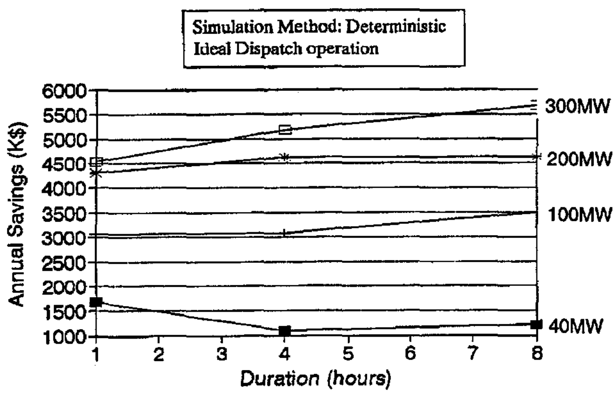
A summary of the annual savings ($K) in operating costs for a BESS used for Load Leveling with Spinning Reserve is shown in Table 2. The nearly straight line graphs of savings for year 1995 are shown in Figure 2.

Table 2. Summary of Annual Savings ($K) for BESS Used for Load Leveling with Spinning Reserve

1995 Ideal Dispatch
Simulation Method: Deterministic

BESS Size (MW)	1 - hour	4-hour	8-hour
40	1,677	1,090	1,215
100	3,071	3,078	3,495
200	4,310	4,625	4,616
300	4,540	5,182	5,678

Figure 2. BESS used for Load Leveling with Spinning Reserve (Year, 1995)



Load Leveling Only

The savings due to Load Leveling Only are not very significant for a short-duration BESS of 1 hour or less. The reason is that most of the peaks are of duration > 1 hour; i.e., a 1-hour BESS cannot shave a peak of duration > 1 hour. Since MWs of generation still must be available (on-line) to serve the peak load, no savings can be made. Even with the BESS power increased from 40 to 300 MW, the dollar ($) savings are still small.

Conversely, as the energy content of the BESS is increased from 1 hour to 8 hours in duration, the savings increase significantly because the BESS is able to shave wider peaks; i.e., peaks of longer time duration. Data for calculation of savings is contained in the utility's hourly load profile, and KCPL happens to have peaks of duration > 4 hours, in general. DYNASTORE uses hourly load profile data for typical weeks out of the year to calculate operating costs/savings.

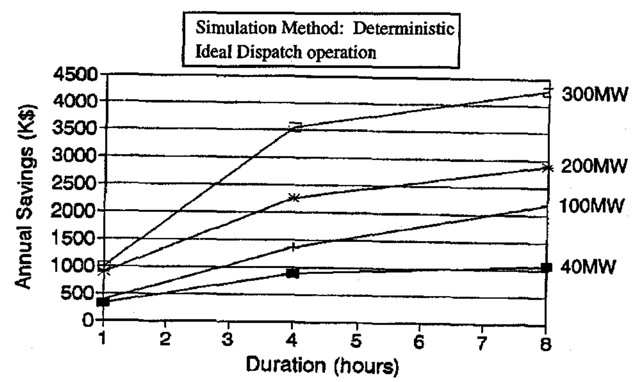
A summary of the annual savings ($K) in operating costs for a BESS used for Load Leveling Only is shown in Table 3. The monotonic increasing line graphs of savings for the year 1995 are shown in Figure 3.

Table 3. Summary of Annual Savings ($K) for BESS Used for Load Leveling Only (no spinning reserve credit)

1995 Ideal Dispatch
Simulation Method: Deterministic

BESS Size (MW)	1 - hour	4-hour	8-hour
40	314	889	1,078.0
100	372	1,355	2,184.0
200	893	2,257	2,896.0
300	989	3,544	4,277.0

Figure 3: BESS used for Load Leveling Only (Year, 1995)



Frequency Control

For Frequency Control (includes driving the Area Control Error (ACE) to zero), the BESS can be used as a substitute for operating a generating unit as a frequency regulator. Placing a generating unit on frequency regulation, in the Unit Commitment sense, requires that the unit be backed down from optimum MW generation in order to have spare MW capacity to pick up a varying MW load in response to raise/lower pulses from the Automatic Generation Control (AGC) system. The BESS is evaluated for this application. Since the National Electric Reliabiliby Council (NERC) requirement is that the ACE must cross zero every ten minutes, the assumption was made that a 1-hour duration BESS provides sufficient energy.

A summary of the annual savings ($K) in operating costs for a BESS used for Frequency Control is shown in Table 4, and the graphs of savings are shown in Figure 4. Note that the savings increase with a BESS power increase, although savings ($K) seem to be leveling off above 300 MW.

Of all the BESS applications, Frequency Control seems to yield the greatest savings, as shown by Figure 4. For this utility, the savings are nearly the same whether higher or lower operating cost units are displaced by the BESS.

Table 4. Summary of Annual Savings ($K) for BESS Used for Frequency Control

Ideal dispatch Operation
Simulation Method: Deterministic
Storage Duration: 1 hour

BESS Size (MW)	Year: 1995	Year: 1996
40	1,481	1,476
100	3,638	4,018
200	5,795	6,268
300	7,149	7,590

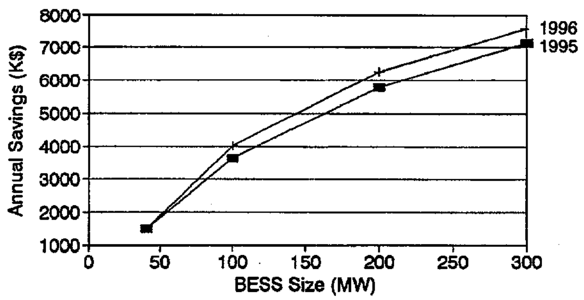
WORK REMAINING FOR A COMPLETE COST BENEFIT ANALYSIS OF BATTERY ENERGY STORAGE

As noted earlier, this project was charged with the responsibility of determining operating cost savings that could be achieved by installing a BESS. To determine total cost savings, the capital costs are also needed for the BESS components listed below. These can be prorated over the life of the BESS:

- Battery: Approximately 1000 cycles for the life of the battery. Consider at least 11% salvage value on replacement of batteries.
- Power Converter System (PCS) - Power electronics should last the life of the BESS.
- Balance of Plant - building, power supplies, HVAC, and controllers should last the life of the BESS.

As several BESSs have been designed and the costs estimated for contract bid, some realistic costs should be available by now for use in cost/benefit analysis studies.

Figure 4. BESS used for Frequency Control



CONCLUSIONS

For a typical midwestern utility (summer-peaking), it has been shown that a BESS can provide savings in operating costs. These savings have been quantified for the following BESS applications:

1) For Spinning Reserve Only, savings increased with MW power capacity up to the spinning reserve requirement (6%), which is approximately 180 MW. The savings then leveled off and decreased slightly as the BESS power was increased from 200 to 300 MW. For the storage time, a duration of 1 hour was assumed, based on experience with other utility applications. Since, a BESS duration of 4 or 8 hours affords no more savings than the 1-hour duration, the smaller duration BESS provides more savings per dollar cost.
2) For Load Leveling with Spinning Reserve, the curves for savings remain fairly flat, and generally increase monotonically (Figure 2). A small storage time BESS tends to be more valuable for Spinning Reserve, whereas a large capacity BESS tend to be more valuable for Load Leveling.
3) For Load Leveling Only, the savings are not very significant for a short duration BESS of 1 hour or less. Even with the BESS power increased from 40 - 300 MW, the savings do not increase significantly. Conversely, as the BESS storage time is increased from 1 hour to 8 hours in duration, savings do increase significantly, because the BESS is able to shave peaks of longer time duration. Hence, the BESS is committed to more peak-shaving time by the DYNASTORE unit commitment algorithm.
4) Of all the BESS applications examined, Frequency Regulation yields the greatest

savings for this utility (Figure 4). The ($K) savings increase with larger BESS power up to approximately 300 MW. For Frequency Regulation, a 1-hour BESS is considered adequate, because of the NERC requirement that ACE be controlled to zero every 10 minutes.

An important contribution of this work was the verification of operating costs by the target utility; i.e., KCPL engineers agreed that our calculated baseline costs were close enough to their actual costs for our model to be an "acceptable/valid" cost model. The inclusion of a spreadsheet to add fixed costs to the DYNASTORE calculated costs enabled the target utility to more easily compare actual operating costs with our calculated costs.

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