Cost Benefit and Alternatives Analysis of Distribution Systems with Energy Storage Systems

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Cost Benefit and Alternatives Analysis of Distribution Systems with Energy Storage Systems

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***Abstract*—This paper explores monetized and non-monetized benefits from storage interconnected to a distribution system through use cases illustrating potential applications for energy storage in California's electric utility system. This work supports SDG&E in its efforts to quantify, summarize, and compare the cost and benefit streams related to implementation and operation of energy storage on its distribution feeders. This effort develops a prototype cost benefit and alternatives analysis platform, integrates with QSTS feeder simulation capability, and analyzes use cases to explore the cost-benefit of the implementation and operation of energy storage for feeder support and market participation.**

***Index Terms*—Cost benefit analysis, energy storage benefits, net present value analysis, markets participation, energy storage dispatch**

I. Introduction

California's energy storage mandate, legislated by AB 2514 and implemented through CPUC D.13-10-040, sets procurement targets for utilities for *viable and cost effective* energy storage systems. This paper focuses on end uses of storage to specific scenarios to help reduce the risk of undervaluing storage as a resource and allow for the identification of utilization opportunities. The tool Cost Benefit and Alternatives Analysis Tool (CBAAT) facilitates the inclusion of energy storage as needs are identified, such as resource adequacy, renewable portfolio standard, and long term resource planning.

A. Contribution from this paper:

Integrating newer devices into legacy utility operations is a challenge and given that these energy storage systems are expensive assets, understanding the cost benefits plays an important role. An energy storage system is a sophisticated, expensive technology yet sensitive to charge/discharge cycle. Investing in an energy storage system is one aspect where as making an asset out of that is a challenging problem. An energy storage system can play a role of a flexible bi-directional source to accommodate issues from constantly varying loads and renewable resources. Utilizing energy storage systems to support distribution feeder operations is helpful, but every charge/discharge cycle reduces the life-cycle of the system. Additionally, the most important aspect is to ensure that the revenue from the energy storage operation should be higher than the cost ascribed to life-cycle cost.

There are commercial tools such as E3 for estimating distributed renewable and energy storage benefits. However, the CBAAT breaks the basic assumptions in cost-benefit framework by directly using the physics-of-feeder by developing a direct link with an open-source distribution system simulator from EPRI, OpenDSS. Figure 1 presents the overall data-flow diagram starting from OpenDSS to CBAAT. A real world feeder will be simulated for multiple years with an increased load each year. This set-up enables CBAAT to capture physics-of-feeder (feeder losses for each time-step, line-currents for assessing upgrades, energy-storage dispatch for evaluating costs etc.) for accurate cost calculations unlike other works in this area.

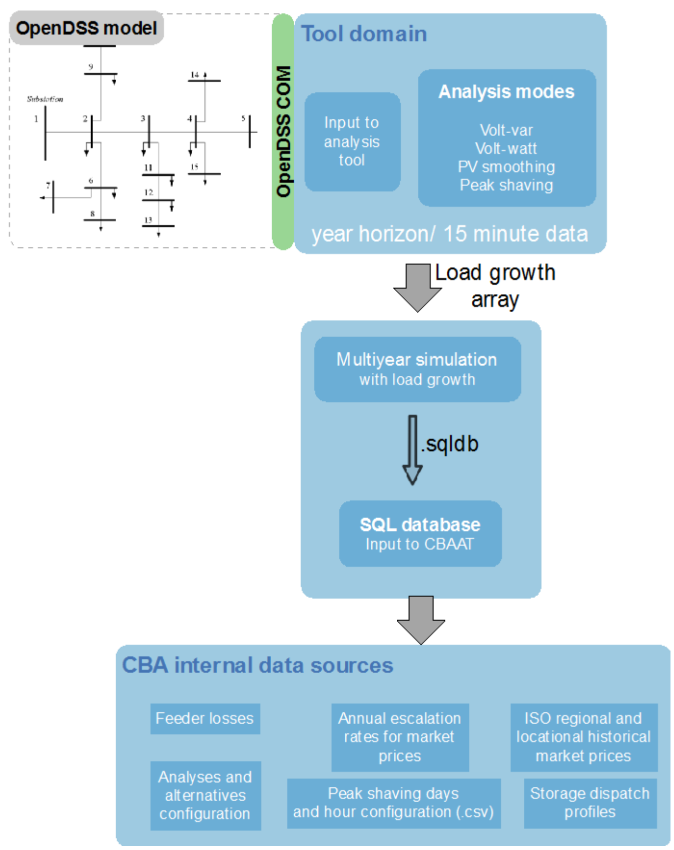

Figure 1 – Diagram representing the overall data flow and operation of CBAAT

The evolution of the process-chain proposed in this paper can be sparsely related to the authors work described in papers presented in the references [1-6]. This paper summarizes the

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comprehensive process-chain and focuses on the further design, functional capabilities, and exercises the CBAAT . This paper is organized as follows: Section II will describe the activity that led to the development of CBAAT, Section III will describe the process-chain for evaluating ESS operation profiles, Section IV will describe CBAAT design philosophy and architecture, and finally Section V will describe the results of the exercise of the tool-chain with application of the CBAAT to different Energy Storage Systems (ESS) dispatch profiles corresponding to different operational objectives.

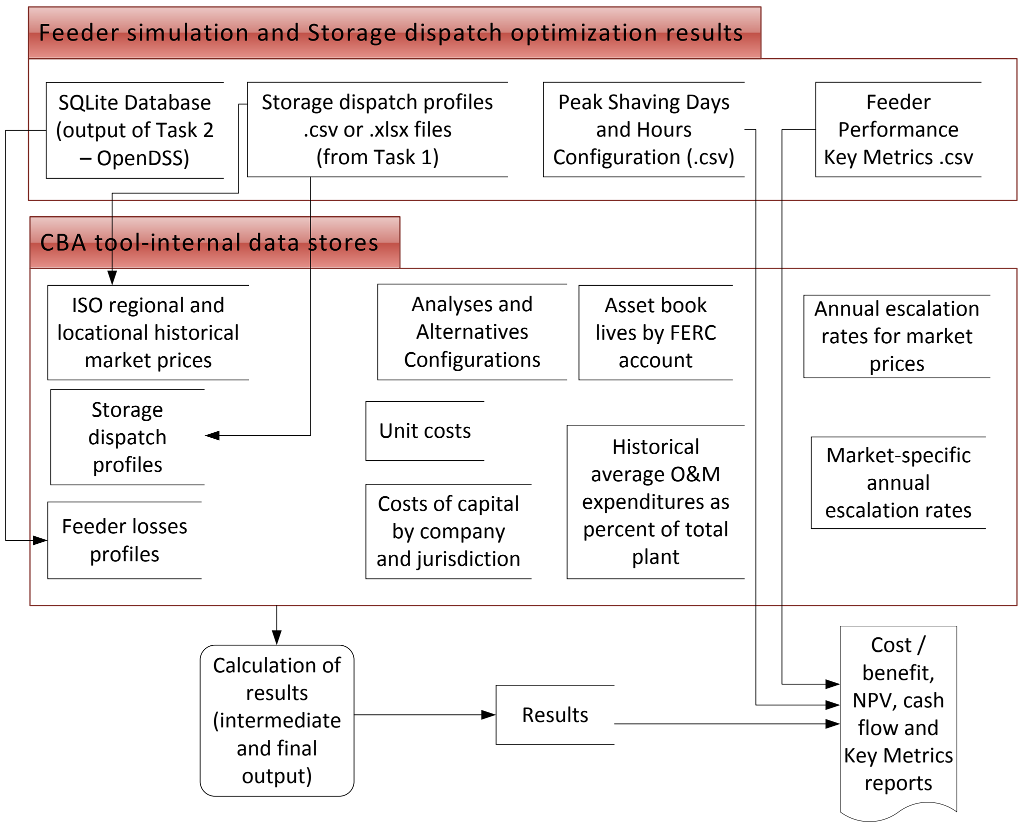

Figure 2 Detailed view of data flows to and from time series feeder simulation showing outputs to use case profile generation and cost benefit analysis

B. Description of activity

In an effort to assess the potential costs and benefits of ESS, we developed a prototype process-chain for San Diego Gas and Electric for feeder simulation, cost benefit alternative analysis of capital investments, and operational profiles of feeders with energy storage. The specific objectives of the CBAAT work were to identify cost and benefit streams associated with ESS, formulate calculations for them, and implement this functionality in a prototype software tool to SDG&E for use in capital and operational planning.

II. Process-Chain Description

This section describes the process-chain for evaluating ESS operation profiles and their corresponding operational cost and benefit impacts. Figure 2 shows the data stores and data flows through the tool-chain.

The diagram gathers internal CBAAT data stores and processes in one group labeled "CBA tool-internal data stores," and groups data stores for result outputs of other tools into a separate categorical group labeled "Feeder simulation and Storage dispatch optimization results." The process and data flows through the tool-chain as follows (some steps are omitted to maintain relevance to the CBAAT focus of this paper):

1. CBAAT configurations are performed: Ancillary Services (AS) and energy market prices, unit costs, costs of capital, asset book lives, historical O&M figures, annual escalation/inflation rates, and framework alternatives for each use case are configured;
2. the CBAAT-external feeder simulation and ESS dispatch optimizations are run and the results are stored in the appropriate data stores;
3. results of the simulation and ESS dispatch are loaded into the framework alternatives that have been configured into the CBAAT;
4. CBAAT queries are run, generating results that are stored in a Results table;
5. cost-benefit cash flow reporting is performed based on contents of the Results table and may be integrated with key feeder performance metrics.

III. CBAAT Functional Capabilities, Accounted-for Value Streams and Design Philoshophy

Given the context of the overall tool-chain, this section describes the capabilities and design philosophy of the CBAAT. The objective for the CBAAT component is to calculate detailed cost-benefit financial metrics on multiple scenarios (alternatives).

The CBAAT calculates financial metrics based on various capital and operating cost configurations, outputs of the feeder simulation, and optimal ESS dispatch modules. It does this for plurality of simulated operating policies, each corresponding to an alternative analysis, as well as comparison and inspection.

A. Added CBAAT Functional Capabilities

This project enhanced the CBAAT to be capable of using price data from energy and ancillary services markets, multiple market-specific annual escalation rates, historical operating and maintenance expenses, approved rates of return, and overhead rates and corresponding rules of applicability

B. Accounted-for Value-streams

NREL and SDG&E selected value streams and agreed upon approaches relevant to the alternative analysis of distributed energy storage implementation and operation. The following cost/value streams were analyzed and approaches decided upon for modeling:

- Equipment, labor, materials
- Property tax
- Tax benefit of depreciation
- Tax benefit of business expense / tax cost of revenue
- Energy generation
- Transmission losses
- Distribution losses
- Load
- Regulation up / down
- Transmission capacity
- Distribution capacity
- Spinning reserve requirements, Non-spinning/replacement reserve requirements, wide-area black-start capability requirements, regulation reserves, contingency reserves, flexibility reserves
- Voltage control
- Increased/decreased O&M, capital expenditures, time-shifting of these
- Battery degradation

1. Fixed Charge Rate (FCR)

Another evolution in tool functionality was to incorporate a proof-of-concept cost normalization capability to stand in for an SDG&E proprietary approach to calculation of the revenue requirement. The revenue requirement is important because regulations require the utility to select projects with the lowest revenue requirement possible within the constraints imposed by its obligation to meet the requirements of its provision of services obligations.

SDG&E decided that in lieu of the calculation of the full revenue requirement, the CBA methodology should utilize a fixed charge rate (FCR) calculation. The FCR is a percentage which, when applied to the total initial capital cost (book value) of an asset, gives a leveled annual revenue amount attributable to the cost of the asset. When this leveled annual revenue amount is applied as a cash flow in each year of the book life of the asset, it represents the annual leveled payments associated with the asset.

Input parameters required for the revenue requirement and/or FCR differed by FERC Uniform System of Accounts account and Sempra company, such as asset book life and federal and state tax treatment. Tracking, organization, and use of these parameters were incorporated into the functionality of the tool.

2. Non-capital expenditures

The CBA tool provides the capability for the manual configuration of non-capital (O&M) expenditures within the unit cost estimating set of functions. It was decided that, in addition to the FCR approach (described above), the CBA tool be able to automatically estimate O&M using the historical figures by FERC account in the way that SDG&E currently estimates O&M for capital projects. This facilitates the use of SDG&E's current approach for capital projects of the type SDG&E had historical data on, and allows for a more detailed, custom estimation of O&M for projects for which there is not historical O&M data (such as storage projects) but for which O&M expenditures needs to be anticipated.

3. Overhead expenses

Overhead calculations were also identified as a key capability for the CBA tool. NREL worked to automate the calculation and application to cash flows of overhead (loaders) utilizing user-pre-configurable loader, loading base, company, fuel type, and "activity type" tables and relationships in the CBA tool. User selections per line item of loading base, company, and fuel type were utilized in actual cost estimation.

C. CBAAT Design Philosophy and Architecture

The design philosophy behind the prototype CBAAT and the tool architecture is addressed in this section. The design involved the management and structuring of data including built data management, user interface, and code for the generation of results.

The relational database model is a collection of stored data organized into multiple tables related to one another using key fields. The rows in a table can reference rows in other tables and can be cascaded in ways that allow the representation of complex data relationships, providing systematic way of managing data.

Though there are performance trade-offs with the use of relational databases, well-designed relational database models can eliminate duplicate data promoting the "single source of truth" best practice (data need only be loaded or updated in a single place and records are always in agreement) and reducing the likelihood of mistakes. Such a model facilitates easy and highly targeted access to information of tightly controllable types, and allows for access to this information through easily generated, potentially complex queries that can systematically join information from many tables at once.

CBAAT was enhanced with user interface elements and code to automate the import of data from other elements of the tool chain. Procedures were implemented to sequence the execution of queries to perform successive operations for value stream calculation, aggregation, accumulation, discounting, and meta-data tagging. Finally, facilities were created for reporting allowing user inspection of results at various levels of aggregation and at any time horizon.

IV. Cost Benefit Alternatives Analysis Results

This section describes the use-cases that were explored to illustrate the value streams for ESS and the results generated by the tool-chain for each use-case. SDG&E and NREL identified three use-cases for demonstrating the cost benefits as follows.

A. Use-case 1: Baseline markets simulation

The markets algorithm generated base case battery dispatch using all the available capacity of the ESS. The results were fed in to the QSTS simulation tool to run power flows and identify technical metrics such as losses and voltage violations. The output from the QSTS simulation tool were fed into CBAAT which approximated the net present value of the revenue requirement and different planning horizons for the use case based on energy-related value streams, capitalization of case-specific asset costs, and O&M expenses.

B. Use-case 2: Market participation and PV smoothing

PV smoothing was performed using the QSTS simulation tool and the results were passed to the markets algorithm. The markets algorithm derived a dispatch profile, constrained inverter allocation for PV smoothing, and the output was fed back to the QSTS simulation tool. The QSTS simulation tool then re-ran power flows accounting for dispatch profiles from the markets algorithm. The outputs from the QSTS simulation tool and markets algorithm were feed into CBAAT, which approximate the net present values of the revenue requirement at different planning horizons.

C. Use-case 3: Markets participation and peak shaving:

Peak shaving was performed using the peak shaving algorithm in the QSTS tool and the results passed to the markets participation algorithm. Markets algorithm derived a dispatch profiles constrained by peak shaving requirements and results were fed to the QSTS simulation tool which was used to re-run the power flows based on the outputs from the markets and the peak shaving algorithms. The outputs from the QSTS simulation tool and markets algorithm were fed into the CBAAT which approximated cumulative net present values of the revenue requirement at various planning horizons.

Table 1 – CBA output for three use-cases

		2016 (0)			**2017 (1)**		
Category	**Sub-Category**	**Use-case 1: Baseline Markets Simulation**	**Use-case 2: Market Participation and PV Smoothing**	**Use-case 3: Markets Participation and Peak Shaving**	**Use-case 1: Baseline Markets Simulation**	**Use-case 2: Market Participation and PV Smoothing**	**Use-case 3: Markets Participation and Peak Shaving**
Levelized Total Capital Cost	WP: None, U: None, Co: None, Cu: All-in Capex of the Battery	**($412,651)**	**($412,651)**	***($412,651)***	**($412,651)**	**($412,651)**	***($412,651)***
Losses: Losses	Losses (NORTHCTY_6_N004 DAM LMP)	**($5,990)**	**($6,009)**	***($5,977)***	**($7,461)**	**($7,482)**	***($7,445)***
Use-case specific utilization	Total	***$10,769***	***$9,701***	***$10,737***	***$11,092***	***$9,992***	***$11,059***
	Energy Cost (Battery Charge) (NORTHCTY_6_N004 DAM LMP)	($8,448)	($11,522)	($8,431)	($8,701)	($11,868)	($8,684)
	Energy Revenue (Battery Discharge) (NORTHCTY_6_N004 DAM LMP)	$19,217	$21,223	$19,168	$19,793	$21,860	$19,743
Frequency Regulation: Frequency Regulation	Total	***$5,090***	***$3,807***	***$5,090***	***$5,243***	***$3,921***	***$5,243***
	Frequency Regulation (AS_SP26 DAM RD)	$873	$630	$873	$899	$649	$899
	Frequency Regulation (AS_SP26 DAM RU)	$4,217	$3,177	$4,217	$4,344	$3,272	$4,344
Cumulative DCF		***($402,782)***	***($405,152)***	***($402,801)***	***($778,781)***	***($783,277)***	***($778,669)***

D. Cost benefit and alternative analysis

Table 1 shows the cost benefit analysis results of all three use-cases. CBAAT outputs a detailed breakdown of the financial results by providing category and subcategory labels for the output dollar values. In the use cases modeled in this work, there was only one capital cost modeled, the "All-in Capex of the Battery," configured as a custom cost in all scenarios. The calculated leveled cost of the $1,000,000 outlay in 2016 (analysis year zero) based on the FCR calculation was $412,651 each year over the assumed asset life of 15 years. This leveled cost did not change among the scenarios.

Dollar values of losses were aggregated over single years and reported under a single category and sub-category. The sub-category was labeled with the market name whose prices were used to calculate the dollar value of the losses.

The category label "Use-case specific utilization" was used to indicate costs and savings associated with charging and discharging the battery for all of energy arbitrage, AS markets participation, and providing PV smoothing and peak shaving. When the CBAAT output report displays more than one sub-category, it displays a total row above the sub-category rows summing the sub-category figures.

The frequency regulation category had associated regulation up and regulation down subcategories which the market participation algorithm often identified as the most lucrative market for which the battery could be used. The figures reported in these (and the total) rows report only the revenues associated with battery provision of these services to the grid. The energy costs and revenues associated with charge and discharge associated with provision of these services are rolled into the use-case specific utilization figures in the energy cost and energy revenue (and total) rows.

Finally, the Cumulative DCF (discounted cash flow) row shows the sums of the discounted cash flows across all categories; and, in years other than simulation year zero, the sums in each year of these discounted cash flows with those of all prior years. CBAAT can also display cumulative DCFs for each category and sub-category for detailed inspection of all components of cost benefit.

First, looking only at figures associated with the AS markets participation and battery charging and dispatch which are largely determined by the market participation algorithm, we see that the largest total dollar value ($15,859 vs $13,508, and $15,827, respectively for the other use cases) is associated with the market-participation-only use case because the battery is not being prioritized for any grid service and can be fully utilized for market participation.

Although the market participation algorithm, which is designed to optimize charge and dispatch of the ESS to maximize cost-benefit of energy arbitrage and AS market participation, does not account for the costs of feeder losses or operational or capital costs other than those of operation of the ESS, the order of the overall net present values (shown in the cumulative DCF row) of the scenarios was the same as the ordering of the DCFs of the market participation subtotals. This is because, even though losses were less costly in the peak shaving use case than in the market-participation-only use case, the difference in cost of losses was not as great as the amount by which revenues from market participation and energy arbitrage were greater in the market-participation-only scenario than in the market participation and peak shaving scenario.

In this study, CBAAT did not take account of costs or savings (if they existed) of effects on other distribution system components that might result from the operating mode of the ESS. It is not known whether, had such costs and benefits existed and been accounted for, the cumulative DCFs of the market-participation-only use case would have been higher than those of the other use cases.

V. Conclusion

This effort demonstrated the suitability of an application developed in a relational database to structure and manage data and the configuration information needed for cost benefit alternatives analysis of utility systems. Microsoft Access was used for relational database and "front end" tools that are well-suited for prototyping this type of application. As a summary the CBAAT prototype was: 1) easily integrated with other components of the tool chain; 2) user-friendly for data input, configuration, and usability of output; 3) capable of generating its results in a reasonable amount of time (less than five min. depending on number and complexity of alternatives); and 4) based on an architecture that is maintainable and susceptible to modification and evolution.

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