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Technical and Financial Evaluation of Battery Energy Storage for Distribution Capacity Upgrades Deferral

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SUMMARY

As the utility industry transitions into the future, new technologies are arising as potentially feasible alternatives to traditional distribution system solutions. Some of these technology solutions have not been analyzed exhaustively in the past even if the particular technology was already available, because the costs of the technology were often seen as prohibitive. However, for some of these technologies the future landscape is expected to change. Battery Energy Storage Systems (BESSs), for example, is a suite of technologies that have been available for a long time, but was neither efficient nor affordable for utility-scale applications. As a result of recent technology enhancements and increased support from stakeholders, the technological performance is increasing while the prices are declining substantially. This makes the applications for distribution system purposes a viable reality. Energy storage technology can be used to defer or even avoid distribution system upgrades such as circuit reconfigurations, substation transformer upgrades or cable replacements. There is a need for analysis and planning tools, including optimization engines that can define the size and the dispatch strategy of the BESS to limit the cost of these projects, and that can facilitate the introduction of energy storage systems as part of the standard distribution planning solutions. This paper will focus on the assessment framework developed and utilized by a distribution utility to evaluate the technical and economic feasibility of utilizing BESSs to defer or avoid significant traditional distribution system upgrades. The approach described is based on a detailed engineering analysis and financial modelling framework developed for evaluating BESSs. The engineering analysis described here utilizes detailed time-series modelling, using distribution planning software automated through the use of high-level scripting language. This would allow a planning engineer to determine the optimal battery energy storage system sizing, both in terms of power (kW) and energy (kWh) as well as the requirement for reactive power capacity for voltage correction. For the financial analysis, the BESS cost models were developed through stochastic forecasting and applied to several battery technologies. Based on storage sizing and technology cost projection models, the battery storage systems were compared to the cost deferral opportunity of traditional capacity upgrade projects forming a detailed benefit-cost analysis that allowed assessing the technology viability for various lengths of investment deferral periods. The final step in the process is a sophisticated and novel process to extrapolate the results to the system-wide analysis to estimate the total beneficial amount of storage on the utility distribution system.

KEYWORDS

Battery Energy Storage, Utility, Distribution Investment Deferral

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1. INTRODUCTION

The utility industry is experiencing a significant transformation, motivated in part by recent technological and communications advancements. While some of these proliferating technologies have been available for a while, many have been cost prohibitive for commercialization and have therefore not undergone exhaustive analysis for utility-scale application. An example of this is Battery Energy Storage Systems (BESSs), a technology which though used to be seen as excessively expensive, current industry and market trends [1] now support the projection of BESSs decreasing considerably in cost over the next years, enabling the utilization of this technology in grid applications previously determined ineffective. While BESSs have already been deployed in the grid for market applications (i.e. Frequency Regulation) [2], there are a number of additional, and potentially complementary use cases that would represent benefits for the utility customers [3]. These applications include but are not limited to grid congestion relief, reliable and safe integration of distributed energy resources (DERs), improved reliability, and as alternatives to traditional distribution system upgrades.

While there are multiple utility use cases worth studying for the integration of BESS to the grid, not all of them are at the same maturity level, nor fully been embraced by legislative and regulatory authorities. The scope of this paper, therefore, focuses on the technical and financial evaluation of BESSs as non-wires alternatives to distribution system capacity upgrades. Energy storage can serve as an alternative to planning solutions that could be used to defer or avoid traditional distribution system upgrades such as circuit reconfigurations, substation transformer upgrades, building of secondary/tertiary feeds, or cable replacements. In order to avoid the projected system overload that would result in the need for investing in system upgrades, the control strategy for the BESSs can dispatch the system energy when necessary so that it supplies the peak load that exceeds the line or the station allowable loading. For a feeder or a substation, this peak can typically be observed during only the few hottest days each year, but those days represent the scenario for which the entire distribution system is planned. In order to relieve these overloads the BESS will be strategically located downstream of the constraining feeder or substation equipment (i.e. substation transformer, cable segment, etc.).

This paper focuses on an assessment performed by a distribution utility to evaluate the technical and economic feasibility of BESSs utilized to defer or avoid significant traditional distribution system upgrades. The remainder of the paper is organized as follows: Section 2 summarizes the methodology utilized for the technical assessment and sizing of the BESS, Section 3 presents the components considered in the Cost Benefit Analysis (CBA), Section 4 describes the methodology developed to extrapolate results to the entirety of the utility system, Section 5 presents results of a case study that illustrate how the methodology is applied, and Section 6 summarizes the major findings of the paper.

2. METHODOLOGY PROPOSED

As discussed in detail in [4], in order to perform an accurate assessment of the technical feasibility of the BESS as a non-wire alternative to traditional distribution capacity upgrades, a comprehensive methodology was developed for sizing BESS for this use case. The sizing methodology leverages system models and performs time-series analysis utilizing distribution planning software to evaluate the performance of the BESS for a given system. This approach utilizes a standard distribution planning software for the analysis, and time-series simulations were incorporated with a scripting console embedded in the planning software. The embedded scripting console utilizes a high-level scripting language to implement both the time-series simulation model as well as charge and discharge algorithms for the BESS.

In preparation for the simulations, the control strategy and algorithms of the desired BESS were defined and programed in the aforementioned scripting console. These algorithms ensure that the current at the substation or at the feeder is kept within the allowable equipment rating by dispatching the energy from the BESS when the power measured downstream of the BESS exceeds the allowable rating. The control algorithm also monitors the BESS State of Charge (SOC), and maintains it within specified limits. This functionality accomplishes the desired peak shaving, which allows for keeping the equipment loading within its allowable limits. Additionally, the control algorithm is designed to perform power factor correction by monitoring the power factor at the point of interconnection (POI) and sourcing/sinking reactive power from the BESS as necessary to keep it close to unity at the POI. Time-series simulations are performed in order to obtain a detailed dispatch profile of the BESS and determine the optimal battery size for a proposed BESS location. Through the simulation, variables of interest such as power flows, voltage, dispatch profiles, and SOC are recorded and exported to a database to allow for further analysis. Initially, the BESS is oversized for the analysis, and the detailed simulation model is run to adjust battery sizing to optimize the BESS sizing to minimize costs while meeting the constraints. The BESS simulation is then re-run to adjust the recorded data and to assure the system is capable to meet the requirements. Generally speaking, the BESS should be sized so that it has enough Power (kW) to support the load that exceeds the rating during the worst condition (1), and enough Energy (kWh) to sustain the load for the total duration of the peak (2). Mathematical formulation of this approach is presented below [4].

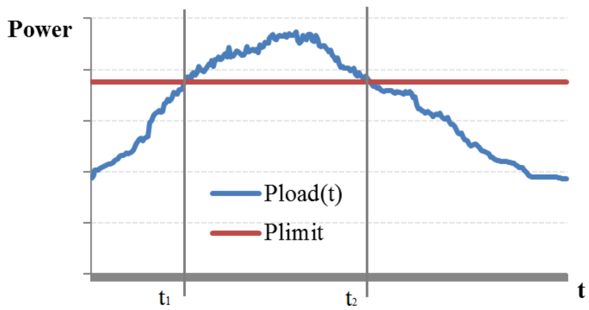

Figure 1: Expected Load (P_{load}) Measured Downstream the BESS and Rating (P_{limit}) Upstream.

$$P_{BES}(t) = \max(P_{load}(t) - P_{limit}) \qquad (1)$$

$$E_{BES}(t) = \int_{t_1}^{t_2} (P_{load}(t) - P_{limit})\, dt \qquad (2)$$

where PBES(t) is the power size of the energy storage, Pload(t) is the expected load measured downstream of the BESS, and Plimit is the rating upstream of the BESS, as shown in Figure 1. EBES(t) is the Energy rating of the BESS to meet the load, and t represents the number of hours BESS would be dispatching energy.

3. COST BENEFIT ANALYSIS

One of the challenges to the adoption of BESS for utility applications has been the high cost of implementation compared to the traditional alternatives. Specifically from the utility perspective, whose ultimate goal is to ensure customer satisfaction providing the best service without unduly impacting customers' bills, this technology must be shown to be economical. A Cost Benefit Analysis (CBA) to evaluate the customer benefits is a key component of the complete evaluation of the feasibility of this solution.

In order to perform this analysis, an automated evaluation model was created to determine the cash flow of the upgrade investment deferral through the BESS solution, as well as the cash flow of the immediate capacity upgrade investment, with the difference between these two solutions being declared as customer benefits, as represented in Figure 2. In the specific analysis of each case, the different cash flows include the estimated cost of the traditional capacity upgrade solution, the estimated cost of the alternative BESS solution including in both cases capital and operational expenditures, depreciation, as well as gains from the deferral of the traditional capacity upgrade investment. The size of battery determined by the technical feasibility analysis described in Section 2 is utilized to calculate the BESS solution costs, based on the estimation of the cost of the technology depending on the size ($/kW, $/kWh) derived from cost models that were developed through stochastic forecasting and applied to Lithium-Ion batteries. The length for the investment deferral is dependent on the cost of investment in each case, therefore it is recommended to perform a sensitivity analysis for different lengths of deferral (i.e. 3 years, 4 years and 5 years) to determine the optimal deferral duration.

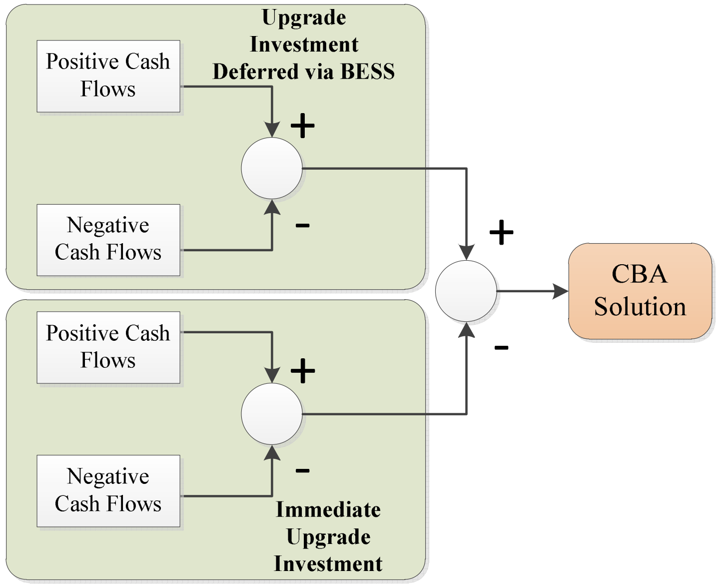

Figure 2: Cash Flows considered for the CBA

4. SYSTEM-WIDE EXTRAPOLATION

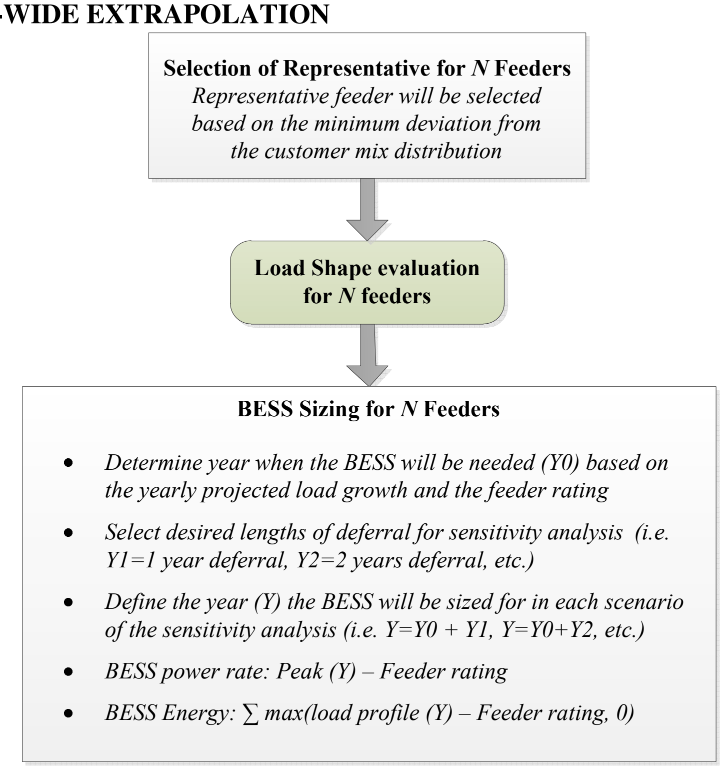

Figure 3: Proposed methodology to size BESS for N Feeders

Characteristics specific to each capacity upgrade deferral project are key input values in order to perform a reliable CBA for capacity upgrade deferral projects. Necessary factors to consider are the projected overload for a specific feeder, cost of the traditional capacity upgrade project, the location where the solution will be installed, as well as the size of the BESS needed to relieve the overload and defer the investment.

The technical evaluation of the solution described in Section 2 that provides the specific load and BESS dispatch shapes to allow for sizing the BESS needed is a sophisticated and time intensive process. This could be bypassed, and an estimation of the real size of BESS needed for each feeder could be approximated making it possible to obtain system-wide CBA estimates.

The methodology proposed for this purpose relies on the characterization of the broader set of N feeders by their distribution of customer mix, in order to group them by similar distributions and assuming the load profiles shape for each of the feeders within the same group match a representative feeder load profile shape, which will be obtained through a complete technical evaluation. The distribution of customer mix is evaluated in terms of percentage of residential (R), commercial (C) and industrial (I) customers. This methodology simplifies the complexity of the analysis and extrapolates the results for the system of N feeders. Figure 3 presents a summary of the sizing process for the N feeders in the system. As stated in the Figure, the first step in order to size the BESS needed is to determine the year in which the BESS system will be required as an alternative to the capacity upgrade. A sensitivity analysis to determine the optimal duration of the deferral is recommended, by evaluating the results of the CBA given different lengths of deferral.

5. CASE STUDY

Assume a utility would be looking into implementing this type of alternative solution to traditional system capacity upgrades, the first natural step might be to analyze its benefit potential through the performance of an estimated system-wide analysis following the methodology described in Section 4. The results from this study would be a good indicator of the potential of the BESS implementation for this use case, providing at least an order of magnitude estimate of the benefits. The second step may call for taking a closer look at the system needs, as well as to the specific characteristics that would make each one of the system feeders a good candidate for this solution. A proposed screening criterion would consider feeders projected to be overloaded in the near future and in need of a capacity upgrade to be performed; feeders for which the capacity expansion is in a specific range (i.e. 1-5MW) and have small projected load growth; feeders for which the traditional capacity upgrade requires a large capital investment. In our study this criterion is followed in order to identify which feeders would generate benefits from the implementation of this solution.

Once the potential candidates have been identified following the methodology proposed, the third step would be to perform a complete assessment of the solution for those specific candidate feeders selected. Below, a sample use case is presented, in order to illustrate the assessment process that would take place at this stage.

The use case presented involves a sample distribution feeder, for which the following conditions have been defined for the purpose of this use case study:

- Current year peak load: 7700 KW
- Current allowable rating: 7800 KW
- Expected load growth: 2%
- Estimated BESS cost: $1000/kW
- Estimated traditional investment cost: $700,000

Table 1: Results of Sensitivity Analysis, Size and Cost of BESS by Length of Deferral

	Minimum BESS Size Required		Commercially Available BESS		Cost of BESS
Length of Deferral	Capacity (kWh)	Power (kW)	Capacity (kWh)	Power (kW)	Approximated Total Cost ($)
3 years	750	500	750	500	600,000
4 years	1300	720	1500	750	1,100,000
5 years	1950	900	2000	1000	1,500,000

The conditions defined a scenario in which the feeder would be overloaded in the following year. Estimated costs of BESS technology and traditional investment are defined based on data collected from vendors as well as from utility distribution planners. In order to determine the optimal size of battery for the deferral of this solution, a sensitivity analysis was performed, considering different lengths of investment deferral (1 year, 3 years, and 5 years of deferral) and performing the technical assessment through simulations described in Section 2 for each of them. The results of this sensitivity analysis are shown in Table 1.

The results obtained reveal that in order to defer the investment for 3 years, the BESS needed cost would be around $600,000, however if the deferral considered is 4 years or longer, the price of the BESS needed increases substantially, providing negative net present value in comparison to the traditional investment, suggesting that in this case the optimal length of deferral of the capacity upgrade investment would be for 3 years. The results from the time-series load flow simulation for the 3 year deferral case are shown in Figure 4, which shows the necessary battery operation in order to achieve the peak shaving, revealing the minimum size of BESS necessary to in order to defer the capacity upgrade deferral. The maximum energy discharge from BESS, tells us the necessary BESS capacity is 750 kWh, while the maximum power injection from the BESS tells us the necessary BESS power rating is 500kW. The results from the CBA under the established assumptions reveal that the benefits derived from the deferral of the traditional capacity upgrade investment would be positive.

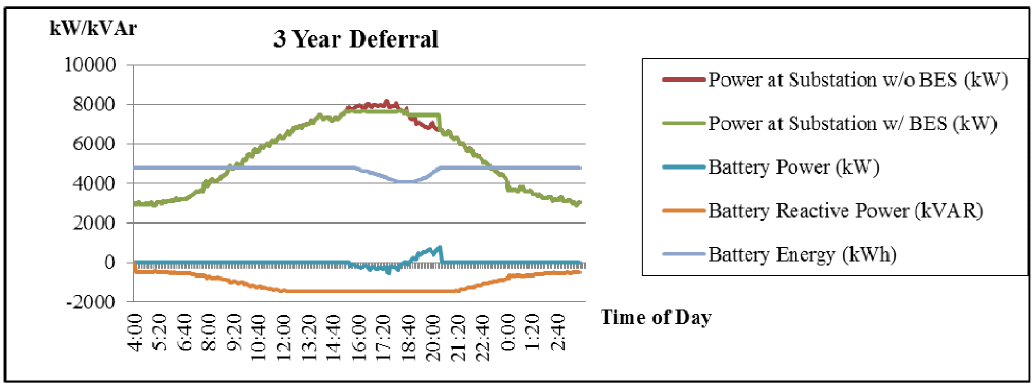

Figure 4: Results from the Time-Series Load Flow Simulation for the 3 Year Deferral

6. CONCLUSIONS

This paper presents a practical methodology proposed by a distribution utility to evaluate the technical and economic feasibility of BESSs utilized to defer or avoid traditional distribution system upgrades. It presents an extension of the work published by the authors in [4] by leveraging the results obtained from the evaluation of the technical feasibility of BESS in representative feeders to defer distribution upgrades to perform a CBA and assess the economic feasibility as well. The case study presented illustrates the application of the described methodology, showing the positive impact on customer economics that this type of solution could have if it is deployed under suitable conditions. This methodology could be advanced in order to include other factors and account for more complex revenue streams that could be leveraged through this application such as arbitrage or wholesale ancillary services.

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