EVALUATION OF ENERGY STORAGE IN DISTRIBUTION SYSTEMS

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ABSTRACT

This paper presents a methodology that has been developed by Electric Power Research Institute (EPRI) to perform the technical and cost/benefit analysis of realizing the potential solution opportunities of energy storage within distribution. The methodology developed was built in terms of identifying and characterizing feeder contrainsts. Key elements of the overall methodology are presented in this paper. This methodology is now being tested through case studies in several utility situations.Results from one example case study is presented in the paper.

INTRODUCTION

Energy storage is receiving increasing attention by utility engineers and regulators alike for its potential to solve a wide number of technical challenges in the management of electric power. Distribution-scale energy storage deployments have increased significantly in the last few years. However, as planning for the demonstrations projects began, the following things became evident:

- There was no common agreement on the domain-, location-specific requirements and grid services for energy storage
- There was no common quantitative based approach to identify the cost-effectiveness of storage with respect to the individual grid services and their associated values
- No standard methodology or tools exist to quantitatively evaluate the effectiveness of storage solutions and compare with traditional distribution level solutions

Technical studies are typically not undertaken to quantify an energy storage system's size and deployment location. The storage systems on distribution system have been deployed ad hoc depending on what manufacturers have offered in terms of rating (MW, MWh) controls, and performance. Traditional distribution planning techniques are well established in the power systems, yet the majority of energy storage systems are deployed in the field without these analyses.

Distribution planners now face the challenge of accurately including the value and impact of energy storage in distribution planning. The most common planning procedures rely heavily on a static power flow of a selected loading condition – usually the peak power demand forecasted for a selected planning period. This does not give an accurate representation of variable resources such as Photovoltaic (PV) generation and limited duration distributed energy resources like energy storage. There is a growing need to accurately consider storage in distribution system planning tools and methods that can evaluate the grid impacts and benefits of energy storage.

The fundamental issue with any of the current tools and methods used for valuation of energy storage is that these valuation analyses are performed on an ad hoc basis. These analyses are typically performed without taking into consideration the technical attributes and operational capabilities of a distribution feeder to which it will connect. For a specific use case, the effects of combining primary grid services benefits with multiple secondary benefits are therefore difficult to evaluate quantitatively.

To address these and related challenges, EPRI have developed a distribution-level energy storage assessment framework to encompass the following key elements:

- Identify use case and requirements that define grid services provided by energy storage on a consistent basis
- Using information from the energy storage usecases and functional requirements perform distribution-level impact assssment of energy storage systems
- Develop tools that can support combining the grid impact findings with cost/benefit analysis of realizing the potenital solution opportunities of energy storage within distribution

This methodology is now being tested through case studies in several utility situations. In each study, simulations are produced to model distribution feeders experiencing various issues that might be addressed through the use of energy storage. The impact of energy storage on the distribution feeder is explored, and the value of the storage relative to alternative solutions is estimated according to specific guidelines.

It is shown that this methodology can provide a reasonable estimate of the primary distribution-focused grid service benefits provided by energy storage systems along with multiple secondary benefits. This result should and will be validated through the actual installation and operation of energy storage systems on feeders where positive value is calculated through this methodology.

OVERALL EPRI ENERGY STORAGE FRAMEWORK WITHIN DISTRIBUTION

The overall EPRI Energy Storage methodology is provided in Figure 1

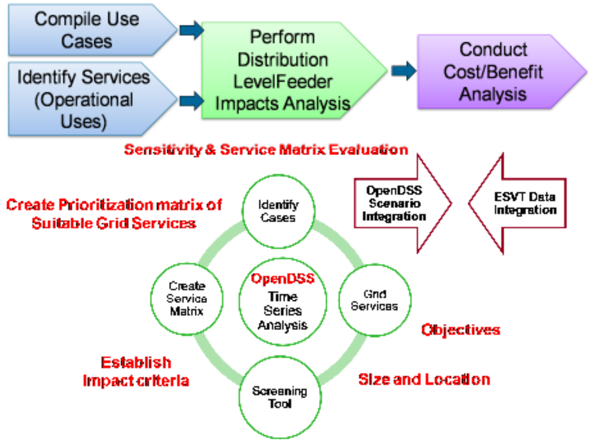


Figure 1: EPRI Energy Storage Methodology for Distribution Systems

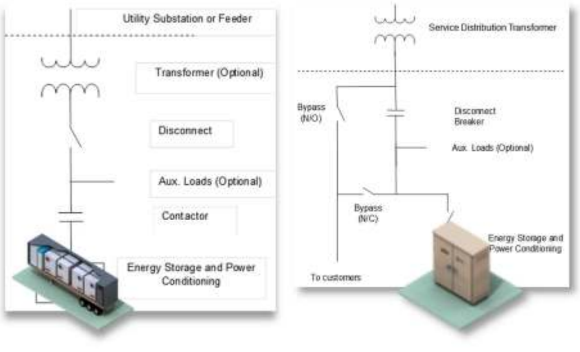
The key elements of the overall EPRI Energy Storage analysis framework are discussed next in the subsequent sections.

Compile Energy Storage Use cases

EPRI Energy Storage Integration Council (ESIC), Working Group 1 (WG1), defined two broad energy storage product categories based on existing research conducted by various stakeholders [1-9]. The resulting set of product categories described below provides the opportunity to develop specific sets of requirements that are based on energy storage size (large-scale versus small scale) and supports developing multiple use cases. The attributes include: 1) Location where the energy storage will be sited, and 2) Grid services that energy storage will support.

- **Large-Scale Energy Storage Systems at Substation Level or Along the Distribution Feeder:** Possible benefits could include: distribution peak capacity support in terms of peak shaving upgrade deferral, investment deferral, distribution operation (Volt/Var support), equipment life extension, service reliability, and on-site firming or shaping intermittent renewable. This storage system could be sited within a utility microgrid setting. It would be sized at 0.5 to 10 MW for 1 to 6 hours.

- **Small-Scale Energy Storage Systems at Edge of Grid:** This edge of grid use case is smaller scale. It provides the same benefits as the larger storage at distribution substation, but would be placed in the utility right-of-way or on customer property facilitated by an agreement and connected to the distribution circuit. This can help improve power quality and service reliability. An additional benefit is to aid where there are high penetrations of PV on a distribution circuit. This storage system could also be sited within a utility microgrid setting. It would be sized for 25 to 500 kW for 2 to 4 hours.

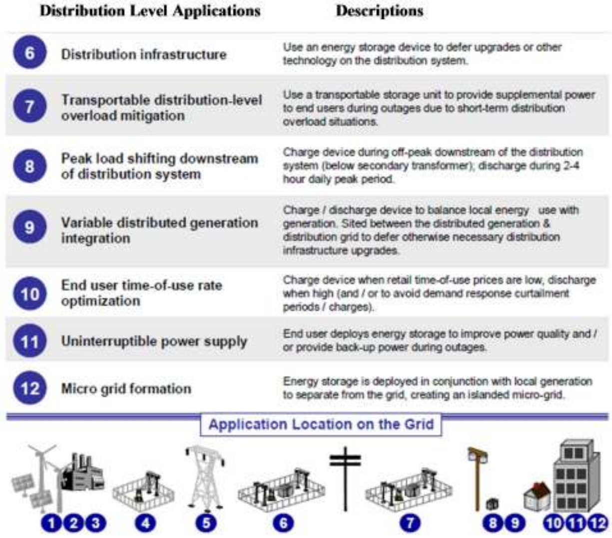


Large Scale Substation/Feeder **Small Scale Edge of feeder**

Figure 2: Large-Scale and Small-Scale Distribution Connected Energy Storage

Identify Grid Services & Operational Uses

In a more recent white paper from Southern California Edison [7], the authors first identified discrete *operational uses* where storage theoretically could be deployed across the electric value chain. *An operational use is a discrete single use for storage that can independently derive value*. Using the operational uses as "building blocks," the authors then developed specific and practical *applications* otherwise defined as a potential operational uses of energy storage across the value chain as a function of both physical location and operating profile. The seven distribution level applications are shown in Figure 3.



	Distribution Level Applications	Descriptions
6	Distribution infrastructure	Use an energy storage device to defer upgrades or other technology on the distribution system.
7	Transportable distribution-level overload mitigation	Use a transportable storage unit to provide supplemental power to end users during outages due to short-term distribution overload situations.
8	Peak load shifting downstream of distribution system	Charge device during off-peak downstream of the distribution system (below secondary transformer); discharge during 2-4 hour daily peak period.
9	Variable distributed generation integration	Charge / discharge device to balance local energy use with generation. Sited between the distributed generation & distribution grid to defer otherwise necessary distribution infrastructure upgrades.
10	End user time-of-use rate optimization	Charge device when retail time-of-use prices are low, discharge when high (and / or to avoid demand response curtailment periods / charges).
11	Uninterruptible power supply	End user deploys energy storage to improve power quality and / or provide back-up power during outages.
12	Micro grid formation	Energy storage is deployed in conjunction with local generation to separate from the grid, creating an islanded micro-grid.

Figure 3: Applications and Locations of Energy Storage on the Distribution Level

In a more recent report [6], DNV GL conducted a survey of representatives from EPRI, 18 utilities, 11 energy storage vendors, 8 consultant or analysts, and 2 other types of stakeholders. From the survey, distribution upgrade deferral, fast regulation, voltage support and service reliability were identified as the most valuable energy storage applications. Another conclusion that was revealed indicated that the most promising way for a energy system to prove its economic feasibility is for that system to perform multiple services on the distribution system. This "stacking" of values is the key to success for storage technology

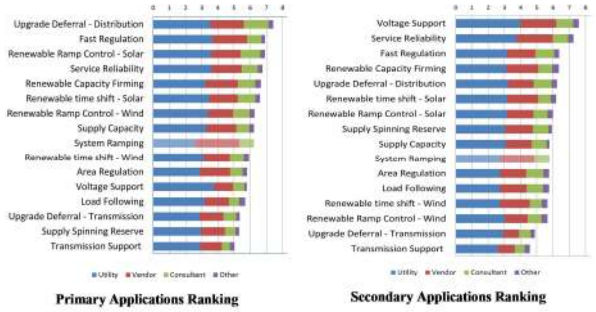


Figure 4: Primary Application Categorized Ranking from NAATBatt Study

As part of the next step, EPRI is working with ESIC WG#1 members to identify the specific usecase that will be used to develop detailed functional requirements.

Distribution Impact Analysis

The purpose here is to develop consistent methodology to understand the potential grid impacts of various deployments scenarios of energy storage on the distribution system. This task entails developing accurate storage models that could be used to study the effect of storage within distribution systems. It also includes conducting technical analysis using simulation and modeling of real distribution feeders as well as studying the operational requirments of energy storage to provide different grid services. Grid impact analysis will improve understanding of answers to the following questions (and others):

- What are the effects of storage deployment on the operations of the distribution system?
- How can energy storage provide localized voltage regulation through Volt/Var operation?
- How can energy storage defer investments in the distribution system?
- How can energy storage shif high penetration renewable production to peak load periods?

EPRI has recognized for more than a decade that in order to evaluate the impact of distributed energy resources within distribution it is not possible to get the correct answer from distribution planning viewpoint unless a series of power flow solutions covering a significant time period were computed. EPRI proposes to use the Open-source Distribution Systems Simulation (OpenDSS) program to conduct energy storage assessment on distribution systems. Figure 5 illustrates the overall framework and includes base feeder model development and steady-state stochastic analysis with distributed generation (DG).

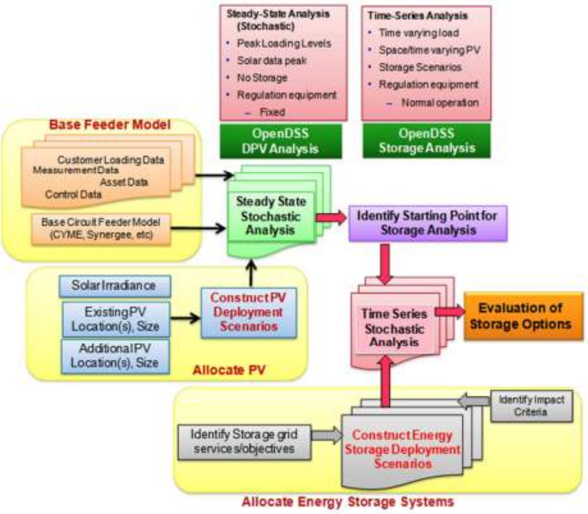


Figure 5: Overall EPRI Energy Storage Impact Analysis Framework

The framework for time-series energy storage analysis is shown in Figure 6. The ***first*** step is to identify the case for initiating the storage analysis. This can be a feeder with existing reliability issues or a feeder where existing DG systems already create voltage concerns or a feeder where planned expansion is likely to cause adverse impact. Overvoltages are generally the primary concern for the power system utility – the steady-state voltage appearing throughout the feeder. The steady state stochastic analysis described in the previous section is designed to provide a starting point for the storage analysis. The steady-state stochastic analysis will identify scenarios/cases where likely impacts of increasing DG penetration would cause adverse impact on distribution operations.

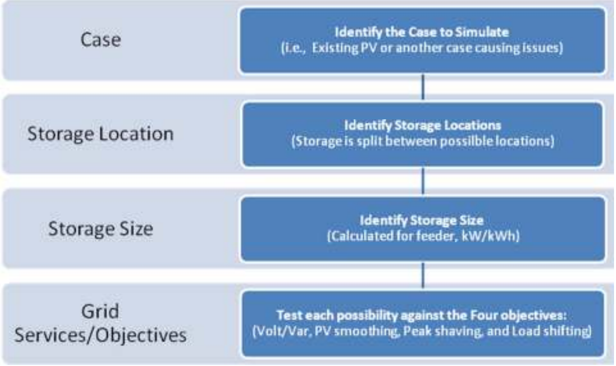
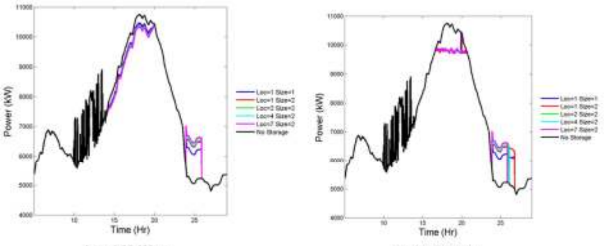


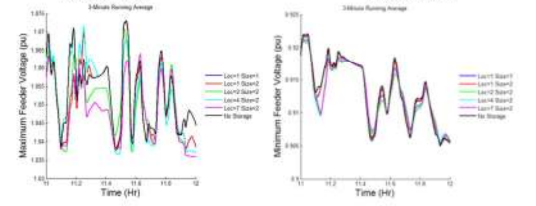
Figure 6: Energy Storage Analysis Framework

The ***second*** step is to look at the feeder under study and identify potential locations for storage. The ***third*** step is to determine the ideal storage size used on the feeder. An approximate energy storage sizing (MW and MWh) can be computed from DG variability data (maximum power deviations from PV output data), peak loading profile (based on % target for peak shaving), and derating factor to account for losses at the power converter and battery. This starting point for an approximate energy storage size can be varied during the time-series analysis.

The ***fourth*** step includes identifying the operational use for storage: 1) Peak Shaving 2) Load Shifting 3) PV Smoothing with volt-var control. The ***fifth*** step involves evaluating different energy storage solutions and grid services based on some defined impact criteria. The goal is to improve the performance of distribution operations with respect to these criteria. Planning criteria and limited have been are already identified by both North American and European distribution standards. The criteria of interest could include: 1) Voltage (overvoltage and voltage deviation, unbalance) 2) Control (regulator, capacitor) 3) Loading 4) Loss/Consumption.



Load Shifting Peak Shaving



Voltage Response for PV Smoothing a) Maximum Voltage b) Minimum Voltage

Figure 7: Energy Storage Operational Use Illustration

Value Analysis of Energy Storage – Combining the Grid Impact Scenario Cases with Value Analysis

The fundamental issue with any of the methods used for valuation of energy storage is that these cost analyses are performed on an ad hoc basis. These analyses were performed without taking into consideration the technical attributes and operational capabilities of a distribution feeder to which it will connect. For a specific use case scenario, the effects of combining primary grid services benefits with multiple secondary benefits are therefore difficult to evaluate quantitatively. Also, it is difficult to quantify the appropriate technical attributes and cost-effectiveness and benefits (cost to benefit ratio) accrued from a storage solution for a specific grid service.

One example is the effectiveness of a storage system to provide volt-var support function at the distribution level. The optimization of voltage and var control is by itself a complex task, which requires a large amount of input data and a sophisticated algorithm. Four differnet control schemes of varying complexity and with different performance implications for volt-var support could be implemented within a energy storage system:
Fixed power factor function, constant reactive power, intelligent volt-var function, and volt-watt function.

If detailed information of a distribution feeder where the energy storage will be deployed is not known (in terms of the following information provided below), then a constant reactive power could be the most simple and technically viable and cost-effective solution to implement within energy storage.

- What are the traditional voltage control resources that are being utilized by the utility for the specific feeder where the energy storage will be deployed
- Where are these traditional voltage controllers sited along the feeder
- What are the operating setting used for these traditional voltage controllers
- What types of voltage and reactive control schemes are currently implemented

If feeder specific information and control schemes are known then an intelligent volt-var schemes and the other schemes described above could offer more potential technical benefits and could ultimately be more cost-effective. These advanced applications will calculate the optimal settings of traditional utility resources (namely voltage controller of LTCs, voltage regulators, capacitor status) and enables storage means to effectively optimize the voltage support operation. In the example shown in Figure 8, a hypothetical battery storage system is assumed to be located within a utility's distribution system.

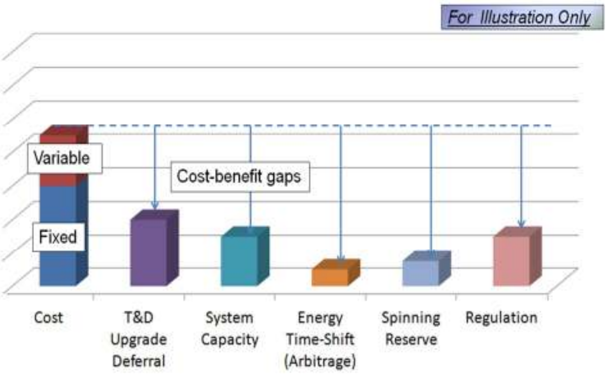


Figure 8: Comparison of Storage Cost Compared to Individual Grid Service Benefits

The energy storage is assumed to be capable of supporting a number of grid services, and no single grid service can support the cost of the storage system. Each of the services shown in the illustrative example may require only a fraction of the operational capability and availability of the energy storage system. For example, the “T&D Upgrade Deferral” may be triggered by a very small number of annual peak load events, perhaps 10 days per year. It is therefore possible that a storage system designed to offload a T&D asset during infrequent peaks may have significant opportunities to provide additional benefits to the electric system. If benefit stacking of this type is done through a systematic approach using actual feeder modeling and simulation, the results could provide a concrete and compelling value for storage in this illustration. The “simple sum” of benefits could be greater than the cost of storage.

EPRI has developed a methodology for separating and clarifying analytical stages for storage valuation and developed the Energy Storage Valuation Tool (ESVT) to support this methodology by enabling user-friendly, customizable, and transparent storage value analysis.
The Valuation Methodology is documented in [12].

It will be necessary to continue to exploit capabilities to accurately account for storage in distribution planning. As evidenced in previous section, at present, there are no industry-accepted methodologies or tools that combine the grid impact scenario cases with the value analysis tools that currently exist for energy storage. Existence of these will enable better decision-making to consider energy storage, and other emerging flexible resources, as an option for cost-effective operation of future grids. EPRI is working to integrate the features of the ESVT tool within OpenDSS. A similar approach is more recently taken by DNV KEMA were they are combining the two framworks together using OpenDSS and DNV KEMA’s Energy Storage Distribution Valuation Tool (ES-BAM) [5].

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