Integration of Energy Storage as a wireless alternative for the Distribution capacity

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Abstract: Energy storage (ES) and other non-wires alternatives (NWAs) to traditional distribution system solutions are gaining popularity in applications including feeder reliability, distribution capacity, and distributed energy resource integration. To assess ES as an NWA, distribution system operators do not yet have defined procedures because ES is not a widely used grid asset. Specifically, it's unclear how ES will affect the different parts of the overall distribution planning procedure and what additional tasks distribution planners would have to do. When considering ES as an NWA for distribution capacity, this paper addresses the extra considerations and analytics that distribution planners must carry out at different stages of the overall distribution planning process.

1 Introduction

Consideration of energy storage (ES) as an alternative to conventional mitigation solutions is seeing increasing interest across the industry. In particular, ES is being increasingly considered for distribution capacity, feeder reliability and distributed energy resources (DER) integration and other applications. This paper focuses on the distribution capacity application, where ES is considered to either avoid or defer distribution capacity upgrades required due to load growth. Distribution capacity upgrade deferral is often viewed as an attractive application for ES as a non-wires alternative (NWA). This is attributed to the cost of some conventional distribution capacity alternatives – such as deploying a new transformer or a feeder – that may compare favourably with the costs of the ES solution. Scenarios in which the distribution system operator (DSO) deploys, owns, and operates the ES are examined here. Different considerations are required for cases where the DSO procures the distribution capacity as a service from third parties and can be found in the literature works [1, 2]. This paper stems from research collaborations between the Electric Power Research Institute (EPRI) and DSOs in the United States and the rest of the world, where EPRI along with the DSOs has assessed various ES scenarios involving stacked distribution, transmission, and wholesale market services.

As ES is not currently a very common grid asset, DSOs have generally not developed established practices for evaluating ES as an NWA. In particular, it is not clear how ES will influence each step of the distribution planning process and what new assessments distribution planners may need to perform. This paper identifies additional considerations and analytics that distribution planners need to perform at four stages of the general distribution planning process when considering ES as an NWA for distribution capacity. Fig. 1 highlights the four steps in the general distribution planning process, where additional considerations and analytics are needed to effectively incorporate ES as an NWA for distribution capacity.

The remainder of this paper has the following structure. Sections 2–5 discuss the additional considerations and analytics in the four steps of the planning process, as illustrated in Fig. 1. Then, Section 6 briefly discusses the role of screening criteria/methods in streamlining the use of planning resources. Finally, Section 7 summarises the paper.

2 Study definition

Study definition is the first step of the general planning process with additional considerations and analytics. This step involves determining the distribution planning criteria and identifying load/ DER forecast and other key inputs for the distribution system assessment.

Distribution planning criteria

Distribution planners need to evaluate how distribution planning criteria apply to ES as an NWA for distribution capacity. Relevant criteria to evaluate include:

† *Loading limits*. Distribution planners should review defined loading limits and their applicability considering the dynamic characteristics of ES. Given the high cost, controllability, and limited energy capacity of ES, it is often desirable to design ES capacity project to operate as close to loading limits as possible.
† *Voltage regulation*. It is important to consider the voltage regulation impacts from ES. Provided it is properly designed, using ES to provide distribution capacity is unlikely to adversely impact the feeder voltage regulation. Analysis is also needed when the ES solution is also leveraged to support the existing voltage regulation.
† *Fault current levels*. Planners need to consider, although likely limited (~1.0–1.3 p.u. of the inverter rating), the impact of the fault current contribution from the ES inverter.

Load and DER forecast

Load (and DER) forecast are not only fundamental inputs to distribution capacity needs assessment, but also directly influence ES requirements when designed to provide distribution capacity deferral. In addition to requirements for accuracy, the increased

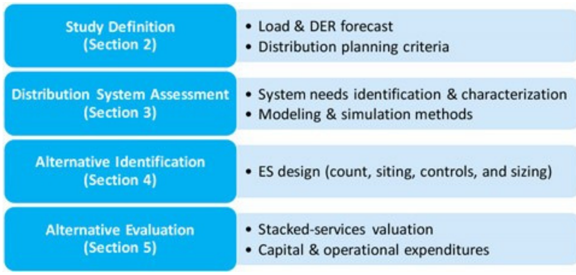

Fig. 1 *Four steps in the general distribution planning process with additional considerations and analytics when considering ES as an NWA for distribution capacity*

granularity of the forecast is required as the forecasts need to represent not only the extreme time instances, such as the peak and minimum load but also the extreme time periods, such as peak and minimum load days or weeks. In particular, the forecasts need to accurately capture the time periods when ES is anticipated to be required to discharge and charge. Given the importance of the load/DER forecast, sensitivity analysis of the ES design and evaluation may be desirable to account for any forecast uncertainties.

3 Distribution system assessment

The second step of the general planning process is the distribution system assessment, which involves identifying and characterizing the distribution system capacity needs.

Fig. 2 illustrates the key inputs and outputs of the distribution system assessment. Based on inputs including distribution planning criteria, load/DER forecast, and distribution system models, the following characteristics of the distribution system capacity needs are identified:

† *Location.* A distribution capacity need may be related to one or multiple constrained distribution assets. ES may be considered as an NWA for some or all of them. An optimal approach to address the capacity need may involve some conventional capacity upgrades in combination with an ES NWA solution.

† *Power and energy requirements.* As conventional distribution capacity solutions are not energy limited, traditional planning only needs to focus on meeting peak system demand. When considering ES for distribution capacity, however, it becomes necessary to consider the energy associated with the capacity needs. A rough estimate of the energy requirements can also be obtained by quantifying the highest energy associated with any forecast loading period above the equipment ratings. Quasi-static time-series (QSTS) load flow simulations are recommended for more detailed assessments of the energy requirements. If the load is forecasted to grow over the analysis time horizon, the power and energy requirements associated with the capacity needs are also expected to grow.

† *Timing.* This refers to when some measures are required to address the distribution capacity needs for the first time. The timing provides the latest time that the storage system can be installed. The timing can be identified from when the power and energy requirements become non-zero.

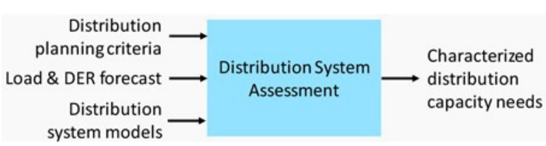

Fig. 2 *Key input and output variables for the distribution system assessment*

4 Alternative identification

The third step of the general planning process with additional considerations and analytics is the alternative identification, which involves designing the ES for the distribution capacity application. The ES design involves identifying the ES count, siting, controls, and size. These aspects are discussed in the following subsections.

ES count

Distribution capacity application can in many cases be addressed with a single ES. Deploying a single ES is also typically more cost-effective as opposed to deploying multiple distributed ESSs. However, if some factors speak for multiple ESs, it is recommended to evaluate a sensitivity scenario with multiple ES in addition to a scenario with a single ES.

ES siting

It is straightforward to identify feasible ES sites for the distribution capacity NWA application in radial distribution systems: the ES simply needs to be located downstream of all capacity-constrained distribution assets. On meshed distribution systems, or on systems with high DER penetration levels, detailed QSTS studies are recommended to evaluate alternative ES sites. Additional aspects related to ES siting include reconfigured feeder conditions, reliability impacts, and other practical aspects such as the availability of low-cost sites, distribution upgrades required to interconnect the ES etc.

ES controls

While distribution planners are likely not responsible for designing ES controls, the planners need to consider the impact of the control on the other aspects of the ES design, particularly the ES sizing. Poorly defined ES controls can yield an ES ineffective providing distribution capacity, or in adverse distribution impacts.

Possible ES control methods can be roughly divided into three categories: schedule-, rule-, and model-based controls. Schedule-based controls are simple to implement but likely less effective compared to more advanced rule- and model-based controls. Hence, schedule-based controls may need to be more conservative and thus, may require a larger storage capacity. Rule-based controls (including feedback controls), when properly designed, can be more effective than schedule-based controls and result in lower storage utilization. More advanced model-based controls may be justified in complex scenarios that, e.g. involve multiple stacked services.

When designing the ES controls, it is also important to consider the monitoring available, including the monitored distribution equipment, the monitored quantity (power versus current), monitored phase(s) (particularly on highly unbalanced circuits). Appropriate control margins should be applied when the available monitoring is limited.

ES sizing

One of the key aspects of the ES design for distribution capacity is to identify the required ES size. ES size has three components: MW rating, MWh rating, and MVA rating. The MVA rating is defined by the inverter. For distribution capacity application, the ES MVA rating could be sized to match the MW rating. However, some stacked services, such as volt-var control, may justify oversizing the ES inverter. QSTS simulations are recommended to identify the required MW and MWh ratings. ES sizing should consider the impact of the ES controls. Note that the ES size identified typically refers to the usable ES rating, which may not be equal to the ES rating specified by the manufacturers. Other considerations related to ES sizing include storage and distribution losses, reactive power compensation, phase unbalance, storage degradation etc.

5 Alternative evaluation

The fourth step is the alternative evaluation. This step involves calculating the capital and operational expenditures, stacked-service revenues (if applicable), and economically comparing different ES scenarios to conventional distribution capacity alternatives.

Stacked-service valuation

Distribution capacity service requires ES to discharge during peak load times that may be infrequent. At other times, there is potential to utilize the ES for potentially multiple stacked services. Table 1 lists selected distribution system, transmission system, and wholesale market services. To perform a comprehensive economic comparison of ES NWA designs and conventional distribution system capacity alternatives, it is necessary to estimate the value/ revenue from stacked services, if any.

Before estimating the stacked-service value, it is necessary to select the stacked services. Similar to distribution capacity service, which is the focus of this paper, the value from other stacked distribution/transmission services comes from deferring investments to conventional distribution or transmission solutions. When no conventional solution is required, providing these services yields no monetary value (there may still be technical value). There are likely only a limited number of sites, where multiple distribution and/or transmission system level services are needed. When selecting the stacked services, it is important to consider their priority/hierarchy. This paper focuses on scenarios, which have distribution capacity as the primary service with the highest priority.

It is important to re-evaluate the ES design (ES count, siting, controls, and sizing) while selecting the stacked services:

† *ES count and siting*. Most stacked services are unlikely to influence ES count. However, stacked services may considerably impact ES siting. Good sites for stacked distribution services, e.g. volt-var control may differ from the site identified for the distribution capacity service. The distribution impacts from the stacked transmission/wholesale market services may also require considering alternative ES sites.

† *ES sizing*. Stacked services may pose additional requirements for ES sizing beyond the minimum size identified for the distribution capacity service. In particular, volt-var control may require an oversized ES inverter MVA rating and some wholesale market services require a certain minimum ES power and/or energy capacity.

† *ES controls*. Providing complex stacked-service scenarios is likely to require more sophisticated ES control methods than providing distribution capacity service alone.

Table 1 Selected stacked services

Stacked-service group	Stacked service
distribution system services	reliability and resiliency distribution volt-var control DER integration/hosting capacity increase asset life extension distribution loss reduction power quality phase balancing
transmission system services	capacity/congestion relief dynamic) volt-var support peaker substitution/peaking capacity blackstart generation and restoration support
wholesale market services	energy time-shift/energy arbitrage flexible ramping frequency regulation spinning and non-spinning reserves resource adequacy

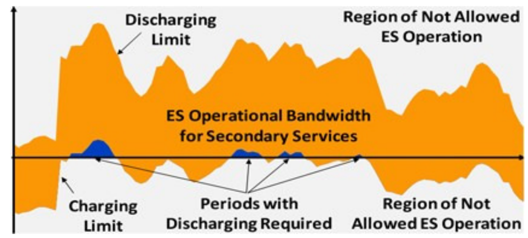

Fig. 3 *ES operational bandwidth for stacked services*

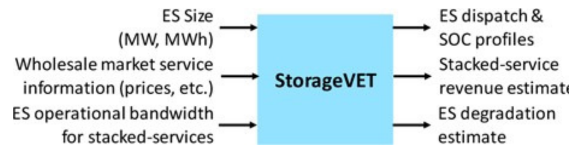

Fig. 4 *Key input and output variables for Storage VET*

Once the stacked services have been identified, it is necessary to estimate the value of stacked wholesale market services, if any. This can be achieved with the aid of *ES operational bandwidth for stacked services*, which captures: (i) distribution capacity service requirements and (ii) requirements of stacked distribution and transmission system services and bounds to avoid adverse distribution impacts from stacked services. Fig. 3 illustrates the concept. For details, see [1].

Stacked-service valuation can be performed with tools such as StorageVET [3] with the key input and output variables illustrated in Fig. 4.

Based on ES size, wholesale market service price and other information, and ES operational bandwidth for stacked services, StorageVET performs time-series storage dispatch optimization to determine the storage dispatch and state of charge profiles and estimate the stacked-service revenues and the storage degradation.

Economic comparison

The following aspects should be considered when economically comparing ES NWA designs to conventional distribution capacity solutions:

† *Timing*. It is important to consider the construction schedules, equipment lifetimes, and the economic analysis time horizon.

† *ES costs*. To compare the storage NWA designs to the conventional distribution capacity alternatives, it is necessary to estimate the storage system capital and operational expenditures. This can be challenging given the limited ES cost data publicly available. Evaluating what a given cost estimate entails is necessary.

† *ES NWA degrees of freedom*. Due to its modularity, it is possible to increase ES capacity if/when a given load growth realizes. It may also be possible to transfer some ES to another site if a forecast load growth did not realize.

6 Role of screening

As is evident from previous sections, complex site-specific analysis can be required to thoroughly evaluate ES as an NWA for distribution capacity. However, such detailed analysis is not always necessary. The use of distribution planning resources can be streamlined by leveraging various screening criteria and methods over the planning process. Once screening criteria are established, streamlined screening processes, methods, and software tools will be needed. Possible screening criteria include:

† *Economic screening* criteria is intended to avoid the need to analyse ES in cases where conventional solutions are likely considerably more cost-effective than ES. Potential economic screening criteria include a minimum cost of the conventional distribution capacity upgrade and the maximum ES size.
† *Technical screening* is intended to identify the required ES capabilities are available from commercial ES solutions. Technical screening is important when considering non-typical ES NWA applications or less common ES technologies.
† *Project lead times screening* are helpful in assessing if the distribution capacity need allows sufficient time to design, procure, and deploy an ES NWA solution, which may have a longer lead time as compared to conventional distribution upgrades.

7 Conclusion

This paper discusses the additional considerations and analytics for distribution planners to be aware of when considering ES as an alternative to mitigate distribution capacity issues. These considerations and analytics are discussed related to defining the planning criteria and inputs, assessing the distribution system capacity needs, designing the ES NWA solution, stacked services, and economic comparison of ES NWA designs and conventional distribution capacity solutions. Streamlining the use of planning resources with the aid of screening criteria and methods is also discussed and is a key focus area for future research and development.

8 References

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