CIGRE-475

2022 CIGRE Canada Conference & Expo
Calgary, Alberta, Oct.31 – Nov. 3, 2022

A Reliability-Driven Battery Energy Storage System Sizing Method for Distribution Radial Supplies

Alexandre Nassif[1,2]
[1]LUMA Energy, [2]ATCO

Puerto Rico, USA

SUMMARY

As costs decline and industry matures, the application of utility-scale energy storage is gradually gaining acceptance in areas where traditional reliability improvement methods are not cost effective. Electrochemical batteries have become a viable option in various applications. The paper presents a utility-adopted method for sizing electrochemical batteries to improve system reliability. This method was derived in an environment where the utility is rebuilding many of its feeders and adopting undergrounding strategies that represent long lead times but necessitate stop gap measures to ensure reliability is improved in the interim.

KEYWORDS

Battery Energy Storage Systems, distribution planning, power system reliability, outage restoration

Alex.Nassif@lumapr.com

1. Motivation

As electric utilities strive to serve customers and to promptly respond to outages, they build experience and can reasonably predict system performance with varying degrees of accuracy. As a result, reliability metrics are often used in the calculation of load not served and subsequently in the preparation of business cases to justify system improvements. restore any component that has suffered an outage.

As the application of non-wires alternatives becomes more popular, utilities have sought applying battery energy storage systems (BESS) as these occasionally build a strong value proposition [1]-[3]. The application of BESS goes beyond increasing reliability, as they can also level off renewable generation [4], improve voltage fluctuations [5], and support the development of microgrids [6]-[7]. With all these additional benefits, many cases have been made for improving SAIDI and SAIFI metrics and power quality improvement. For example, a reliability constrained planning was proposed in [8] for rural systems, although some of the required parameters in this reference are not accessible to the utility as they pertain to internal measurements of the BESS. Another work presented in [9] utilizes BESS to develop microgrids and further highlights the future reliance on BESS by utilities. A framework for related applications is presented in [10], but a common limitation of all these methods is that they require parameters not measurable by utilities.

A practical sizing method for BESS that includes financial data proprietary to utilities is necessary to adequately address system issues and create a solid business case. This paper presents a method that only relies on (1) a quantification of unserved load, (2) outage reports, and (3) storage and grid upgrade pricing information. The results of this analysis revealed that grid edge portions of a grid can result in an ROI as short as two years.

2. Formulation

The key valuations used in this work are outage frequency and duration impacts on customer served, as well as the cost of equipment.

The Objective Function

The objective function is a search that seeks minimizing the entire cost of the project that includes the BESS investment and the value of lost load (VoLL):

$$f = C_{VoLL} + C_{BESS\_CAPEX} + C_{BESS\_OPEX} + C_{BESS\_Losses} + C_{Grid_{upgrades}}, \qquad (1)$$

where C_{VoLL} is the cost assigned to the VoLL, C_{BESS_CAPEX} is the CAPEX assigned to the BESS, C_{BESS_OPEX} is the OPEX cost assigned to the BESS, C_{BESS_Losses} is the cost of the operating losses of the BESS, $C_{Grid_{upgrades}}$ is the cost associated with the distribution system network upgrades that include, as a minimum, a new sectionalizing recloser, BESS step-up transformer, sensors and controller. The annualized losses are calculated as:

$$C_{BESS\_Losses} = BESS_{KVA} \times (1 - \varepsilon_{rt}) \times 8{,}760, \qquad (2)$$

where ε_{rt} is the inverter efficiency associated with switching losses. While the BESS inverter does not continuously operate at full duty, this expression captures other losses such as the continuous energy consumed by the BESS and recloser controllers.

Quantification of VoLL

The financial impact on a customer goes well beyond the cost of unbilled electricity. In fact, the cost of an unserved load that supports community lifelines vastly overshadows the uncaptured energy cost by a utility. VoLL can be calculated by assigning a cost value per unserved kWh for each customer class and using one several methods, two of which are considered in this paper [11]:

- Jurisdictional comparison to obtain a blended cost per unserved kWh.
- The Interruption Cost Estimate (ICE) calculator [12] which calculates a cost per unserved kWh and a cost per event. This is the approach used in this paper.

Estimating the total unserved kWh during typical outages leads to uncertainty, due to load profile variation as well as data not being available at a customer level. Power flowing on portions of feeders is also not available as monitoring in distribution networks is typically sparse. Systems with high load factor are more manageable and assumptions can be made. Furthermore, systems that typically experience very long outages (in the order of 24hours) become more manageable as daily consumption can be used to extrapolate the average kW.

Another item is the cost of interruption, as outputted by [12]. This tool categorizes customers as residential, small commercial and industrial, and medium and large commercial and industrial. It does not have provisions to account for critical loads such as health facilities with operation rooms. The case study in this paper addresses a system supplying critical facilities and the author had to assume the outage cost for such facilities is 30% higher than those of small commercial and industrial.

BESS CAPEX and OPEX Costs

The following calculations were used to estimate the costs associated with the BESS:

- C_{BESS_CAPEX} was defined through quotations from various vendors.
- C_{BESS_OPEX} was estimated assuming a truck roll per month for a visual inspection, even though the equipment will be under warranty for the first several years.
- C_{BESS_Losses} was calculated assuming continuous switching losses of 8% and escalating by the energy wholesale costs.
- $C_{Grid_{upgrades}}$ is the cost of recloser, transformer and associated equipment.

3. Case Study: Rural Feeder Supplying Critical Loads

Fig. 1 shows the system driving this project. A 38 kV – 8.32 kV substation steps down subtransmission voltage to distribution utilization. The substation contains an on-load-tap-changer and two feeders supplying mostly a town center as well as the load of a national park, which contains 39 critical facilities deemed critical, although consume little energy. These include telecommunication towers, aviation equipment, a police station as well as water pumps. The original supply to the national park was feeder 02. However, the area was destroyed by a hurricane in 2017 and due to inaccessibility and environmental restrictions, the utility was unable to rebuild this feeder. Feeder 01 also experienced extensive hurricane damage, but repairs were possible. As a result, one of the affected critical customers built a 5 km private underground extension to tap on feeder 01, which became the only available supply to the facilities. Fig. 1 represents the loads and system current feeder configuration.

The utility created a plan to transfer the park and critical facilities loads to a different substation with an entire underground supply, a plan that is in the 4-5 year time horizon.

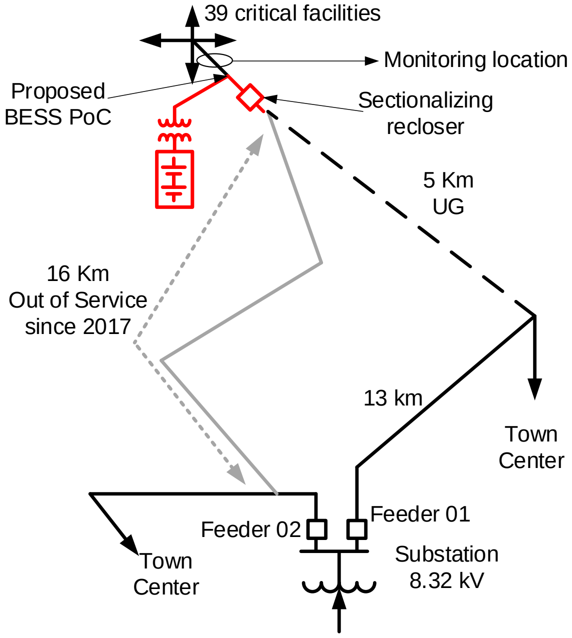
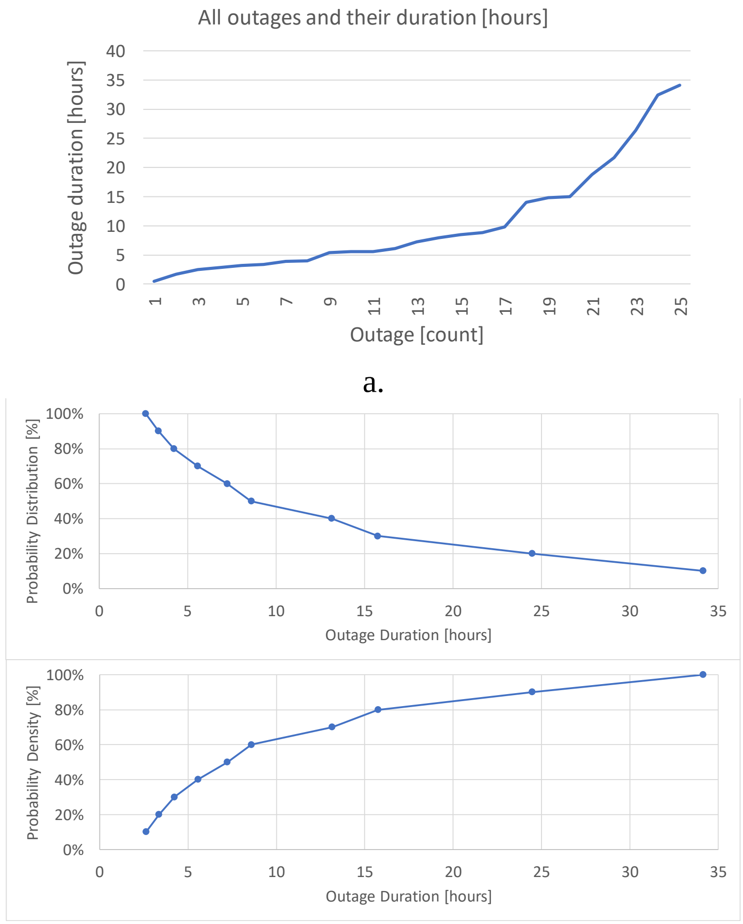


Fig. 1. System topology.

Outage Restoration and Downtime

Most of the feeder running through the heavy forested park comprises of insulated wired. However, it still experiences many outages with long repair times. Outage information was collected for outages occurring in this line segment. Fig. 2 shows this outage information collected for a period of two years (2018 and 2019). To note, as this is a blue-sky reliability analysis, extreme events were removed manually. Note the 10th percentile outage is about 160 minutes and the 50th percentile outage is 516 minutes.



a.

b.

Fig. 2. Outage information, (a) duration and (b) probability functions.

Reliability Metrics

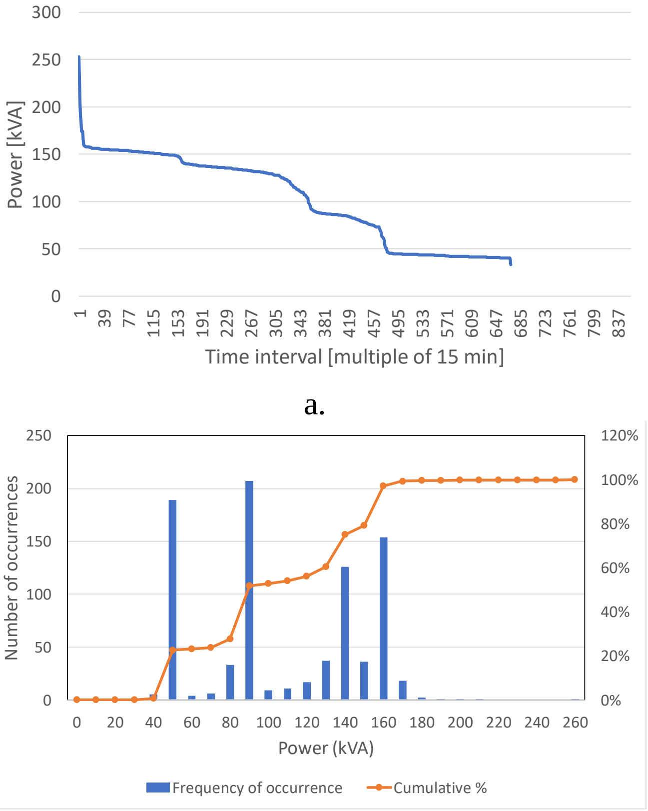
The annualized reliability metrics displayed in Table 1 were calculated for a two-year period. The average outage duration exceeded 3 hours and on average customers experienced over 12 outages per year. These SAIDI and SAIFI values were derived from the customer-minute-interruption (CMI) and customer-interruption (CI).

Table 1. Baseline Reliability Metrics

CMI	CI	SAIDI	SAIFI	CAIDI
504,988	1,221	207	12.5	17

Loading Information

The critical loads are a strong driver, but their load profile is uncertain, as they are metered using electromechanical meters. To baseline the load, current sensors were deployed and connected at the location illustrated in Fig. 1. These current sensors measure all three phase currents but only capture magnitude, hence the load is baselined in volt-amperes. Fig. 3 shows the monitoring results, suggesting low load factor, the 50th percentile equates 87 kVA and average 102 kVA. The figure also shows the load histogram and cumulative distribution.



a.

b.

Fig. 3. Loading information, (a) load duration curve, (b) loading histogram and cumulative probability distribution.

Parameters and results

Although the BESS alternative is relatively fast to implement, it is still likely a two-year project. This suggests it may operate for as little as another two years until the permanent underground supply solution is in place. Hence, it is only economical if ROI is less than two years. As part of the optimization function in equation (1), the estimates contained in Table 2 were created.

Table 2. Cost Estimates

BESS OPEX	**BESS ε_{rt}**	**Electricity $**
$12,000/year	92%	$0.2/kWh

The electricity cost was used to estimate the switching losses. BESS size was varied from 350kWh to 5,000kWh in the optimization search space. The cost of BESS as well as grid upgrades are omitted to protect confidential information. The results of this analysis are shown in Fig. 4, which shows the calculations using equation (1) for a project lifecycle of two years and based on the annualized reliability metrics in Table I. The criticality of the load reflects the high cost of its calculated VoLL which was estimated at $8.8M USD. The results demonstrated that even a BESS system of about 3.5MW is proven economical, but the optimum BESS value is found as 1MW, which is the minimal cost solution.

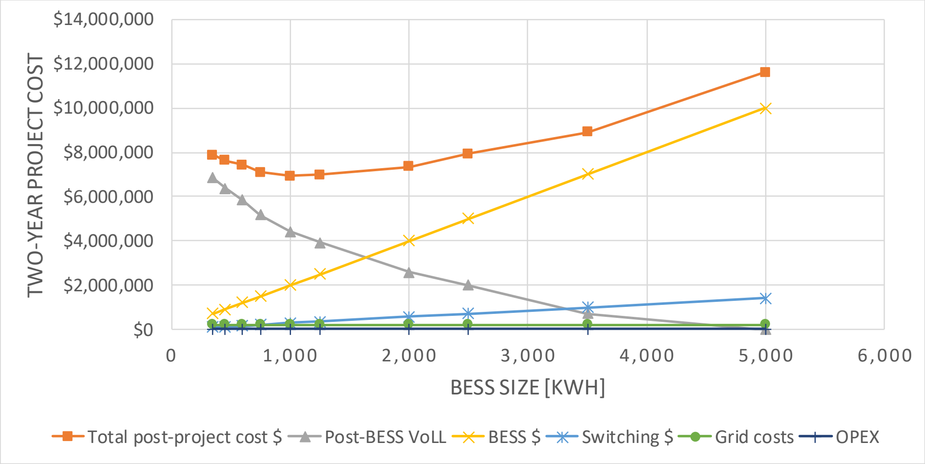


Fig. 4. BESS sizing optimization solution compared with baseline VoLL.

Table 3 shows the impact of this solution on the reliability metrics if a 1MW BESS is adopted. As expected, there is a major reduction in all the parameters. SAIDI is expected to be reduced by more than 50% and SAIFI by more than 60%. CAIDI is expected to increase by more than 30%, demonstrating that reducing the number of outages that are easier to repair increases the percentage of outages that are difficult to repair.

Table 3. Previous and Forecasted Reliability

	Pre-Project	**Post-BESS**	**Reduction**
CMI	504,988	139,993	72%
CI	1,221	209	83%
SAIDI	207	98	52%
SAIFI	13	5	64%
CAIDI	17	22	(32%)

4. Conclusions

This paper introduced a practical sizing method to adopt BESS as a reliability driven non-wires alternative. This method is deemed practical because it only relies on parameters readily available to the utility and not requiring advanced monitoring that is typically unavailable. The largest uncertainty of adopting non-wires alternatives, namely its sizing method, is then removed, and the rest of the problem can then be addressed by using various optimization methods existing in literature.

This paper presented a case where adopting a BESS as non-wires solution is economical even as an interim solution to long-term projects.

BIBLIOGRAPHY

[1] C. D. Rodríguez-Gallegos et al., "A Siting and Sizing Optimization Approach for PV–Battery–Diesel Hybrid Systems," in IEEE Transactions on Industry Applications, vol. 54, no. 3, pp. 2637-2645, May-June 2018, doi: 10.1109/TIA.2017.2787680.
[2] K. Lai, X. Wu and A. J. Conejo, "Co-optimizing the Siting and Sizing of Batteries and the Siting of Isolation Devices in Distribution Systems," in IEEE Transactions on Power Delivery, doi: 10.1109/TPWRD.2021.3111643.
[3] I. N. Moghaddam and B. Chowdhury, "Battery energy storage sizing With Respect to PV-induced power ramping concerns in distribution networks," 2017 IEEE Power & Energy Society General Meeting, 2017, pp. 1-5, doi: 10.1109/PESGM.2017.8273881.
[4] H. Nazaripouya, Y. Wang, P. Chu, H. R. Pota and R. Gadh, "Optimal sizing and placement of battery energy storage in distribution system based on solar size for voltage regulation," 2015 IEEE Power & Energy Society General Meeting, 2015, pp. 1-5, doi: 10.1109/PESGM.2015.7286059.
[5] M. J. E. Alam, K. M. Muttaqi and D. Sutanto, "Battery Energy Storage to Mitigate Rapid Voltage/Power Fluctuations in Power Grids Due to Fast Variations of Solar/Wind Outputs," in IEEE Access, vol. 9, pp. 12191-12202, 2021, doi: 10.1109/ACCESS.2021.3051283.
[6] T. Kerdphol, Y. Qudaih and Y. Mitani, "Battery energy storage system size optimization in microgrid using particle swarm optimization," IEEE PES Innovative Smart Grid Technologies, Europe, 2014, pp. 1-6, doi: 10.1109/ISGTEurope.2014.7028895.
[7] F. Nejabatkhah, Y. W. Li, A. B. Nassif and T. Kang, "Optimal design and operation of a remote hybrid microgrid," in CPSS Transactions on Power Electronics and Applications, vol. 3, no. 1, pp. 3-13, March 2018, doi: 10.24295/CPSSTPEA.2018.00001.
[8] A. Narimani, G. Nourbakhsh, A. Arefi, G. F. Ledwich and G. R. Walker, "SAIDI Constrained Economic Planning and Utilization of Central Storage in Rural Distribution Networks," in IEEE Systems Journal, vol. 13, no. 1, pp. 842-853, March 2019, doi: 10.1109/JSYST.2018.2852630.
[9] N. Sakthivelnathan, A. Arefi, C. Lund, A. Mehrizi-Sani and D. Stephens, "Marginal Cost of Reliability Improvement for Standalone Microgrids," 2021 31st Australasian Universities Power Engineering Conference (AUPEC), 2021, pp. 1-6, doi: 10.1109/AUPEC52110.2021.9597729.
[10] X. Shen, M. Shahidehpour, Y. Han, S. Zhu and J. Zheng, "Expansion Planning of Active Distribution Networks With Centralized and Distributed Energy Storage Systems," in IEEE Transactions on Sustainable Energy, vol. 8, no. 1, pp. 126-134, Jan. 2017, doi: 10.1109/TSTE.2016.2586027.
[11] Puerto Rico Integrated Resource Plan 2018-2019, available at https://aeepr.com/es-pr/QuienesSomos/Ley57/Plan%20Integrado%20de%20Recursos/PREPA%20Ex.%201.0%20IRP%202019%20PREPA%20IRP%20Report.pdf
[12] Interruption Cost Estimate calculator, available at Icecalculator.com