This is a repository copy of *DC to turnkey : an analysis of the balance of costs for behind the meter BESS at commercial/industrial sites*.

White Rose Research Online URL for this paper:
https://eprints.whiterose.ac.uk/174825/

Version: Published Version

5th Annual CDT Conference in Energy Storage & Its Applications, Professor Andrew Cruden, 2021, held virtually

DC to turnkey: An analysis of the balance of costs for behind the meter BESS at commercial/industrial sites

D. Roberts, S. Brown*

University of Sheffield, Sheffield, England, S10 2TG, United Kingdom

Abstract

Accurate estimation of the balance of costs required to deliver a turnkey battery energy storage system (BESS) is highly important for decision making on optimal battery type and sizing for a given project. Such costs can be greater than the direct current (DC) boundary module costs for short duration systems. Despite this, very little data is publicly available for such costs at the commercial/industrial scale, and data decomposed into $/kW, $/kWh and fixed components is even scarcer. In the present work, cost models reported by PNNL and Lazard are tested against cost instances reported by EPRI. As system duration increases the Lazard model increasingly overpredicts balance of costs, whereas the PNNL model increasingly underpredicts them. This is due to the former placing more costs in the $/kWh category. It is shown that averaging the PNNL and Lazard models gives better agreement with the EPRI data than either does alone (10% discrepancy compared to 36/30%). The disagreement in cost scaling requires further attention, as it currently hinders the study of longer duration systems.
© 2021 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Peer-review under responsibility of the scientific committee of the 5th Annual CDT Conference in Energy Storage & Its Applications, Professor Andrew Cruden, 2021.

Keywords: Energy storage; Techno-economic analysis; Turnkey price; EPC; Balance of system

1. Introduction

Understanding the costs of battery energy storage systems (BESS) is highly important for policy commitments in the context of the decarbonization drive. Given that the DC module costs of lithium ion systems have fallen substantially in the last five years, the focus on the balance of costs becomes more important. Indeed, for a 1MW/1MWh Li-ion installation, non-battery costs have recently been estimated at 60%–65% of the total upfront costs [1,2]. These costs include the additional hardware required to connect the battery to the grid, installation costs, permitting and setup fees for financing.

For a given application, selection of the optimal BESS type, power rating and duration and would ideally be informed by accurate estimates of the three cost types identified by Eckroad, i.e. those that scale with power rating,

---

those that scale with energy rating and fixed costs [3]. Additionally, Eckroad highlighted the fact that there are cost gaps, where even the best informed analysts will be unaware of the current costs of items due to confidentiality or uncertainty. In academic studies, a $/kWh cost is often used as the sole cost component for the BESS, however, when determining the optimum size for a behind the meter BESS installation, it would be ideal to have information on the cost breakdown according to the three headers above. When modeling a behind-the-meter system in the California region (CAISO), Fisher et al. found that shorter duration BESS give higher revenue per kWh than longer systems, as the incremental revenue from peak shaving and ancillary decrease with duration [4]. In reality additional power dependent costs will push the balance in the other direction. Similarly, any fixed costs will make a larger system more attractive. Unfortunately, where balance of cost breakdowns are publicly available, the above format is not generally observed, and breakdowns are given for specific instances only (commonly a fixed power rating with several durations) [1,5]. Also, some cost components scale with both energy and power rating [1].

In this work, appropriate data on the balance of costs associated with a turnkey behind-the-meter BESS are surveyed and synthesized in order to identify where areas of uncertainty lie. The work is made more challenging by the following factors:

- Data for industrial scale behind-the-meter systems is more scarce than utility scale and residential scale.
- Different studies use different terms and breakdowns.
- Some studies provide a limited number of absolute sizing cases with insufficient degrees of freedom to deconvolute the scale dependency of costs.
- Different studies show costs scaling in different ways.
- Data come from different years.

The survey was initially restricted to sources that publish deconvoluted costs on a per kW and per kWh basis. As the sector is subject to ongoing cost reductions, only data for installations after 2018 were included. However, as only two sources were found for such data, an additional dataset published by EPRI detailing instances of similarly scaled behind-the-meter systems was used to corroborate the per unit cost models [5].

2. Methodology

The data obtained in a search for balance of system costs in a decomposed format are shown in Table 1.

Table 1. Post 2018 cost data obtained for turnkey BESS systems (excluding DC module cost) where breakdown in $/kW and $/kWh terms is given.

Source	Ref.	Year	Scale	BESS	$/kW	$/kWh	Other
PNNL	[7]	2018/2025	Various	Li-ion	BOP(100/95)[a] PCS(288/211)	C&C (101/96)	–
				VRFB	BOP(100/95)[a] PCS(350/211)	(190/180)	–
Lazard	[8]	2019	1MW/2MWh	Li-ion	Inv. & AC system (205)	BOS (104)	EPC @ 51% of hardware.

BOP: "balance of plant", BOS: "balance of system hardware", C&C: construction and commissioning, EPC: engineering and procurement.
[a](Present/Future).

Figures for inverter and AC cost in the Lazard study and 2025 PCS cost in the PNNL study are in close agreement, indicating there is a low level of uncertainty regarding this cost in the near term. The placement by Lazard of balance of system costs in the $/kWh column is in contrast to both the PNNL study, and the aforementioned McKinsey and NREL reports, which show minimal dependence of this cost on energy rating [1,2]. Lazard's expression of EPC as a fraction of the total hardware cost does seem reasonable, as there are likely to be both power and energy rating dependent components, e.g. the installation of cabling and the preparation of the site respectively. The Lazard figure is particularly high, even in comparison to its own estimates for a 100 MW utility scale project (EPC @ 15% of hardware) and a 6 kW residential project (EPC @ 19% of hardware). The EPC fraction used by Lazard for behind the meter Commercial projects has increased steadily since v2.0 in 2016. From v2.0 to v3.0 in 2017, the increase in EPC fraction from 16% to 25% was justified by reports from industry participants of cost increases [6,7]. However,

Lazard also state that the cost of the hardware has fallen faster than the cost of installation, at least for Li-ion batteries, hence the apparently high value for EPC as % of hardware may not be unrealistic.

In the PNNL study, the construction and commissioning costs are 88% higher for a VRFB, because the authors used energy density as a predictor of site area, in the form of a "footprint factor" A similar, but smaller factor (54%) was applied by EPRI when comparing costs for 20 MW/80 MWh systems [8]. This is clearly an area where some uncertainty exists.

The data given in Table 1 were used to construct simple models of EPC and BOSH (balance of system hardware) to obtain a turnkey Li-ion system. C&C in the PNNL report is relabeled EPC. For the Lazard model, where the EPC is a fraction of the hardware costs, a price of $285 is used for the Li-ion DC module, this being the average of the figures applied in [9] and [10].

In order to corroborate these models, an EPRI report dealing specifically with behind the meter cost estimates was consulted [5]. This resource would be ideal for the current purposes, but only specific instances are reported in the free summary, rather than per kW and per kWh costs. The models are thus used to give a prediction for each of the instances, which are compared to the EPRI estimates.

3. Results and discussion

EPC and BOS cost estimates for a lithium-ion system are shown at three energy: power specifications in Fig. 1.
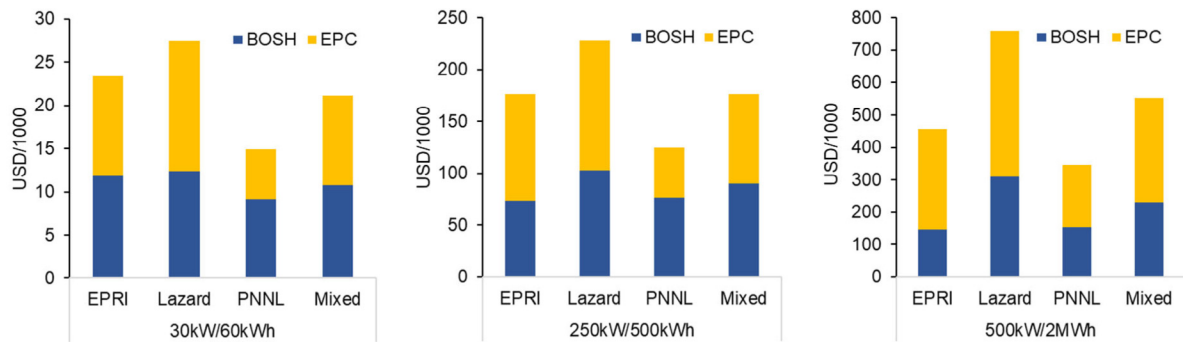
Fig. 1. Comparison of modeled EPC and BOSH costs for Li-ion systems at three system specifications relevant to commercial and industrial BTM applications. "Mixed" refers to the average of the Lazard and PNNL models.

It may be observed that the Lazard model gives a higher estimate for EPC costs than the PNNL model, especially at higher energy to power ratios. This is because the former expresses EPC as a fraction of total hardware costs, some of which scale with energy rating. The format of the EPC cost in the Lazard model is not satisfactory from a general perspective, as drops in the cost of the DC module directly impact the EPC cost, which does not seem realistic. The historical trend in Lazard's EPC cost estimates also suggests that applying this factor outside of this moment in time would lead to error. That said, the PNNL model appears to significantly underestimate the EPC cost when compared to the EPRI data, hence the Lazard estimate acts as a more conservative counterweight. In the BOSH category, the PNNL estimate agrees more closely with the EPRI one, suggesting that the Lazard approach of having some hardware cost components scaling in $/kWh may be flawed.

Overall, the best agreement to the EPRI instances is obtained by averaging the outputs of the two models. When this is done the discrepancy between the prediction and the EPRI instance is 10% on average across the three scales shown in Fig. 1, whereas it is 30% (overestimate) for the Lazard model and 36% (underestimate) for the PNNL model.

It is also worth noting that in the EPRI data, the ratio of EPC to BOSH costs changes with absolute scale when the energy: power ratio is held constant, whereas both the Lazard and PNNL models are absolute scale independent. On closer analysis, the BOSH cost in the EPRI report decreases slightly with scale, which is consistent with either volume discounting, or the presence of fixed costs. The EPC cost by contrast increases slightly, showing that there may be a discontinuity in costs. This implies that applying a per unit cost across a range of scales may be inappropriate.

4. Conclusion

In this work we have reviewed the literature on EPC and balance of hardware costs for behind the meter BESS at the commercial/industrial scale in order to obtain cost estimates expressed in deconvoluted power and energy capacity terms. We found such data to be scarce, and the two sources that do report such data disagree on the dependence of both EPC and BOSH on power and energy capacity. The Lazard model was found to overestimate EPC costs when compared to three cost instances reported by EPRI, whereas the PNNL model underestimated them. The PNNL model gave better agreement on BOSH costs, particularly at longer durations where the Lazard model deviates considerably from the EPRI data.

It was found that averaging the cost models of Lazard and PNNL gave better agreement with the EPRI cost instances overall. The latter showed evidence of either cost discontinuities across the studied range, or fixed costs, which are not captured in either the Lazard of PNNL models. Additional uncertainty in EPC cost will be present when comparing across BESS type, as illustrated by the application by PNNL and EPRI of differing scaling factors related to energy density for a VRFB.

Although uncertainties in turnkey system costs remain an issue, until these are resolved, the used of the mixed model described here is recommended as a more robust approximation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

References

[1] Frankel D, Kane S, Tryggestad D. The new rules of competition in energy storage. McKinsey & Company; 2018, Available from: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-new-rules-of-competition-in-energy-storage. [Last Accessed: 10/02/2021].

[2] Fu R, Remo T, Margolis R. 2018 U.S. Utility-scale photovoltaics- plus-energy storage system costs benchmark. National Renewable Energy Laboratory; 2018, Available from: https://www.nrel.gov/docs/fy19osti/71714.pdf. [Last Accessed: 10/02/2021].

[3] Eckroad S. Vanadium redox flow batteries: An in-depth analysis. Technical report 3, The Electric Power Research Institute; 2007, Available from: http://www.paredox.com/foswiki/pub/Trash/TrashAttachment/EPRI_-_Vanadium_Redox_Flow_Batteries_2007_.pdf, [Last Accessed: 10/02/2021].

[4] Fisher M, Apt J, Whitacre JF. Can flow batteries scale in the behind the meter commercial and industrial market? A techno-economic comparison of storage technologies in California. J Power Sources 2019;420(2019):1–8. http://dx.doi.org/10.1016/j.jpowsour.2019.02.051.

[5] Damato G. Energy storage technology and cost assessment: Executive summary. EPRI; 2017, Available from: https://www.epri.com/research/products/000000003002012046. [last accessed: 10/02/2021].

[6] Lazard. Lazard's levelized cost of energy storage analysis – version 2.0. 2016, Available from: https://www.lazard.com/media/438042/lazard-levelized-cost-of-storage-v20.pdf. [Last Accessed: 10/02/2021].

[7] Lazard. Lazard's levelized cost of energy storage analysis – version 3.0. 2017, Available from: https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf. [Last Accessed: 10/02/2021].

[8] Minear E. Energy storage technology and cost assessment: Executive summary. EPRI; 2018, Available from: https://www.epri.com/research/products/3002013958. [Last Accessed: 10/02/2021].

[9] Mongird K, Fotedar V, Viswanathan V, Koritarov V, Balducci P, Hadjerioua B, Adam J. Energy storage technology and cost characterization report. PNNL; 2019, Available from: https://energystorage.pnnl.gov/pdf/PNNL-28866.pdf. [Last Accessed: 10/02/2021].

[10] Lazard. Lazard's levelized cost of energy storage analysis – version 5.0. 2019, Available from: https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf. [Last Accessed 10/02/2021].