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Battery Energy Storage Systems as an Alternative to Conventional Grid Reinforcement

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ABSTRACT

The upcoming transformation from internal combustion vehicles to electric vehicles in the private transport sector, together with the increasing demand for electricity, leads to challenges such as over-loading for the power grid. This study shows an economic analysis to what extent storage systems can be an alternative to conventional grid reinforcement. Current and predicted costs for storage systems are compared with the costs for cable replacement in the medium-voltage grid and correlations are derived. Accurate co-simulations of storage systems and the distribution grid allow these cost scenarios to be applied to use cases. The results show that the energy related costs for storage systems decrease about 38.5 % from 468 $/kWh to 288 $/kWh from 2020 to 2030. This leads to scenarios, mainly in urban distribution grids, where storage systems are an alternative to conventional grid reinforcement.

Keywords: battery energy storage, grid reinforcement, grid integrated energy storage, energy management system, lithium-ion battery, economic analysis

NOMENCLATURE

Abbreviations	
BESS	battery energy storage system
e^{rate}	energy rate of the battery energy storage system
LIB	lithium-ion battery
LV	low voltage
MV	medium voltage
open_BEA	open battery models for electrical grid applications
SimSES	simulation of stationary energy storage systems

Parameters & symbols	
c_{BEES}	specific energy costs in $/kWh
c_{Grid}	specific grid reinforcement costs in $/km
Cap	maximum economic capacity in kWh
cap	length-specific capacity in kWh/km
d	discount factor
fit_1, fit_2	fitting parameters
l	length of grid reinforcement in km
r	discount rate
t_{BESS}	depreciation period of the BESS
t_{inv}	year of the investment
$t_{inv,c}$	year of the investment, corrected
t_{Grid}	depreciation period of the cables

1. INTRODUCTION

Increased electricity demand, mainly caused by electric vehicles and heat pumps, together with new generator units such as wind and solar power plants poses new challenges for the distribution grid [1]. While in rural areas, the increased share of renewable energies, resulting in over voltages is the main cause of grid reinforcement, in urban distribution grids, it is forecasted that over-loading will be the main driver therefore [2].

In the literature, various approaches exist to avoid grid reinforcement. Especially in the field of electric vehicles, a number of researches deal with controlled charging strategies or Vehicle-to-Grid approaches [3,4]. Battery energy storage systems (BESSs) are seen as an alternative without influencing owners of electric vehicles [5]. Due to the decreasing costs of lithium-ion

4.3 Results *and Discussion*

The four cables in the MV grid, which are beyond their limits, are relieved with a BESS and economically assessed. The results are showed in Fig. 4 for rural areas (a-c) as well as for urban areas (d-f).

BESS 1 (x) with a capacity of 1400 kWh is only competitive in a few cases, despite the long distance (17.62 km) of cable reinforcement that it avoids. Especially in urban areas this scenario only appears when storage costs are falling rapidly and grid reinforcement costs are high. If both remain in the base scenario, this BESS would only be worthwhile in 2030.

BESS 2 (○) with a capacity of 1100 kWh, on the other hand, is not competitive with conventional grid reinforcement. This is because the distance of the cable to be extended is only 6.66 km. Even in urban areas and in the best case for storage (year 2030, subplot d) the costs are identical.

The two storage systems with the least capacity required, BESS 3 (□) and BESS 4 (+), are in all cases competitive with conventional grid expansion. Due to the low capacity (100 kWh each) and the relatively long cable distances (12.45 km and 15.37 km), these BESSs are cheaper even with slightly decreasing storage costs and in rural areas.

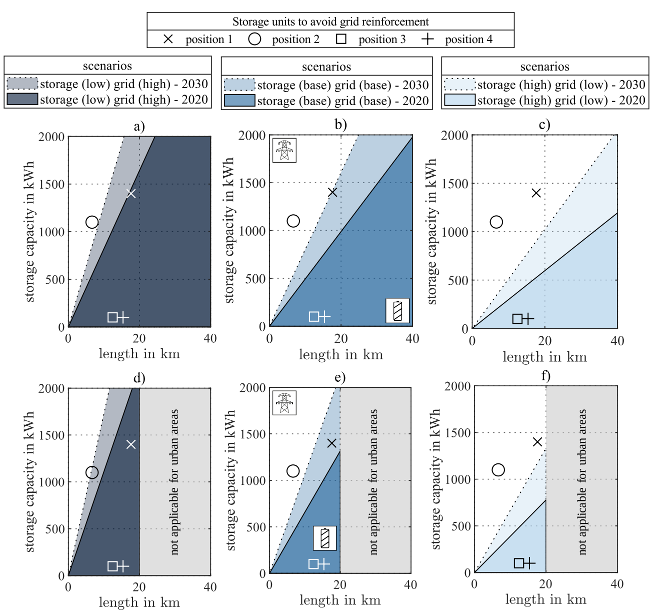

Fig. 4. Classification of the four battery energy storage systems avoiding grid reinforcement in the economic correlation. Subplots a) to c) for rural areas and subplots d) to f) for urban areas.

5. CONCLUSION AND OUTLOOK

This study shows an economic analysis to what extent storage systems can be an alternative to conventional grid reinforcement. Current and predicted costs for storage systems are compared with the costs for cable replacement in the MV grid and correlations are derived. Accurate co-simulations of storage systems and the distribution grids allow these cost scenarios to be applied to use cases.

An economic analysis of storage systems is conducted for BESSs capacities in a range between a few 100 kWh up to some MWh. Three scenarios are derived from the available data. The results show that between 2020 and 2030 the specific energy costs decrease about 38.5 % from 468 $/kWh to 288 $/kWh in a base scenario. To describe each scenario by a cost function, curve-fittings are performed.

The four investigated cases of cables extensions can be avoided by integrating BESS with a peak shaving strategy in the distribution grid. Therefore, the storage capacity is determined with an iterative procedure considering the loads at the positions with grid reinforcement.

The results show, that mainly in urban areas, BESSs can be competitive with conventional grid reinforcement now and even more in 2030. Especially, if small storage capacities are necessary to avoid grid reinforcement, grid operators should consider the possibility of a BESS integration.

5.1 Outlook

In future studies, ancillary services, such as frequency containment reserve, can be assigned to the BESS with the aim of making it more competitive. In addition to an economic analysis, an ecological assessment would allow a more precise investigation of the differences between conventional grid reinforcement and BESSs installation.

Furthermore, smart charging strategies or the potential of Vehicle-2-Grid at residential as well as public charging locations can be used to reduce the stress on the distribution grid resulting from a high EV-share. The simulation tools presented in this study might be used to investigate the effect of these strategies on the distribution grid.

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AUTHOR CONTRIBUTIONS

Daniel Kucevic: Conceptualization, Methodology, Software, Investigation, Writing - Original Draft **Rebecca Meißner:** Methodology, Software, Formal analysis, Writing – Original Draft, Visualization **Andreas Jossen:** Writing - Review & Editing, Supervision **Holger Hesse:** Methodology, Writing - Review & Editing, Supervision

REFERENCES

[1] Stecca M, Ramirez Elizondo L, Batista Soeiro T, Bauer P, Palensky P. A Comprehensive Review of the Integration of Battery Energy Storage Systems into Distribution Networks. IEEE Open J. Ind. Electron. Soc. 2020:1.

[2] Resch M, Bühler J, Klausen M, Sumper A. Impact of operation strategies of large scale battery systems on distribution grid planning in Germany. Renewable and Sustainable Energy Reviews 2017;74:1042–63.

[3] Crozier C, Morstyn T, McCulloch M. The opportunity for smart charging to mitigate the impact of electric vehicles on transmission and distribution systems. Applied Energy 2020;268:114973.

[4] Brinkel N, Schram WL, AlSkaif TA, Lampropoulos I, van Sark W. Should we reinforce the grid? Cost and emission optimization of electric vehicle charging under different transformer limits. Applied Energy 2020;276:115285.

[5] Das CK, Bass O, Kothapalli G, Mahmoud TS, Habibi D. Overview of energy storage systems in distribution networks: Placement, sizing, operation, and power quality. Renewable and Sustainable Energy Reviews 2018;91:1205–30.

[6] Schmidt O, Hawkes A, Gambhir A, Staffell I. The future cost of electrical energy storage based on experience rates. Nat. Energy 2017;6:17110.

[7] Rubino L, Capasso C, Veneri O. Review on plug-in electric vehicle charging architectures integrated with distributed energy sources for sustainable mobility. Applied Energy 2017;207:438–64.

[8] Kucevic D, Englberger S, Sharma A, Trivedi A, Tepe B, Schachler B et al. Reducing grid peak load through the coordinated control of battery energy storage systems located at electric vehicle charging parks. Applied Energy 2021;295:116936.

[9] Kucevic D, Tepe B, Englberger S, Parlikar A, Mühlbauer M, Bohlen O et al. Standard battery energy storage system profiles: Analysis of various applications for stationary energy storage systems using a holistic simulation framework. Journal of Energy Storage 2020;28:101077.

[10] Naumann M, Truong CN, Schimpe M, Kucevic D, Jossen A, Hesse HC. SimSES: Software for techno-economic Simulation of Stationary Energy Storage Systems. In: International ETG Congress 2017: Die Energiewende blueprints for the new energy age proceedings November 28-29, 2017, World Conference Center, Bonn. Berlin, Offenbach: VDE Verlag; 2017, p. 442–447.

[11] Zakeri B, Syri S. Electrical energy storage systems: A comparative life cycle cost analysis. Renewable and Sustainable Energy Reviews 2015;42:569–96.

[12] Frankel D, Kane S, Tryggestad C. The new rules of competition in energy storage. [August 19, 2021]; Available from: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-new-rules-of-competition-in-energy-storage.

[13] Figgener J, Stenzel P, Kairies K-P, Linßen J, Haberschusz D, Wessels O et al. The development of stationary battery storage systems in Germany – A market review. Journal of Energy Storage 2020;29:101153.

[14] Hawaiian Electric Companies. Book 3 of 4. In: The Honorable Chair and Members of the Hawaii Puvlic Utilities Commision, editor. PSIPs Update Report. Honolulu; 2016.

[15] Badeda J, Meyer J, Sauer DU. Modeling the influence of installed battery energy storage systems on the German frequency containment reserve market. In: Schulz D, editor. NEIS 2017: Conference on Sustainable Energy Supply and Energy Storage Systems Hamburg, 21-22 September 2017. Berlin: VDE VERLAG GMBH; 2018, p. 315–321.

[16] Hledik R, Chang J, Pfeifenberger J, Lueken R, Pedtke JI, Vollen J. The Economic Potential for Energy Storage in Nevada. [August 26, 2021]; Available from: https://www.brattle.com/news-and-knowledge/publications/the-economic-potential-for-energy-storage-in-nevada.

[17] Tsiropoulos I, Tarvydas D, Lebedeva N. Li-ion batteries for mobility and stationary storage

applications: Scenarios for costs and market growth. Luxembourg; 2018.
[18] International Energy Agency. World Energy Outlook 2019. [August 26, 2021]; Available from: https://www.iea.org/reports/world-energy-outlook-2019.
[19] Mongird K, Viswanathan VV, Balducci PJ, Alam MJE, Fotedar V, Koritarov VS et al. Energy Storage Technology and Cost Characterization Report. [August 26, 2021]; Available from: https://www.energy.gov/eere/water/downloads/energy-storage-technology-and-cost-characterization-report.
[20] Mongird K, Viswanathan V, Alam J, Vartanian C, Sprenkle V, Baxter R. 2020 Grid Energy Storage Technology Cost and Performance Assessment. [August 26, 2021]; Available from: https://www.pnnl.gov/ESGC-cost-performance.
[21] Deutsche Energie-Agentur GmbH (dena). dena-Verteilnetzstudie: Ausbau und Innovationsbedarf der Stromverteilnetze in Deutschland bis 2030. [August 19, 2021]; Available from: https://www.dena.de/themen-projekte/projekte/energiesysteme/dena-verteilnetzstudie/.
[22] Rehtanz C, Greve M, Häger U, Hagemann Z, Kippelt S, Kittl C et al. Verteilnetzstudie für das Land Baden-Württemberg. [August 19, 2021]; Available from: https://www.baden-wuerttemberg.de/de/service/presse/pressemitteilung/pid/verteilnetzstudie-fuer-baden-wuerttemberg-veroeffentlicht-1/.
[23] Pieltain Fernandez L, Gomez San Roman T, Cossent R, Mateo Domingo C, Frias P. Assessment of the Impact of Plug-in Electric Vehicles on Distribution Networks. IEEE Trans. Power Syst. 2011;26(1):206–13.
[24] Energynautics GmbH, Öko-Institut e.V., Bird & Bird LLP. Verteilnetzstudie Rheinland-Pfalz. [August 26, 2021]; Available from: https://energynautics.com/de/referenzen/verteilnetzstudie-rheinland-pfalz/.
[25] Braun M, Krybus I, Becker H, Bolgaryn R, Dasenbrock J, Gauglitz P et al. Verteilnetzstudie Hessen 2024 - 2034. [August 26, 2021]; Available from: https://www.energieland.hessen.de/verteilnetzstudie_hessen.
[26] Kneiske T, Czajkowski C, Lohmier D, Spalthoff C, Thurner L, Kupka J. ANaPlan - Automatisierte Netzausbauplanung im Verteilnetz. [August 26, 2021]; Available from: https://www.iee.fraunhofer.de/de/projekte/suche/2018/ANaPlan-automatisierte-netzausbauplanung-im-verteilnetz.html.
[27] E-Bridge Consulting GmbH. Moderne Verteilernetze für Deutschland: (Verteilernetzstudie). [August 26, 2021]; Available from: https://www.bmwi.de/Redaktion/DE/Publikationen/Studien/verteilernetzstudie.html.
[28] Harnisch S, Steffens P, Thies HH, Monscheidt J, Münch L, Böse C et al. Planungs- und Betriebsgrundsätze für ländliche Verteilungsnetze: Leitfaden zur Ausrichtung der Netze an ihren zukünftigen Anforderungen. [August 26, 2021]; Available from: http://elpub.bib.uni-wuppertal.de/servlets/DocumentServlet?id=5890.
[29] Tretschock M, Greve M, Probst F, Kippelt S, Wagner C, Rehtanz C et al. Gutachten zur Weiterentwicklung der Strom-Verteilnetze in Nordrhein-Westfalen auf Grund einer fortschreitenden Sektorenkopplung und neuer Verbraucher. [August 26, 2021]; Available from: https://www.wirtschaft.nrw/pressemitteilung/verteilnetzstudie-nrw.
[30] Battke B, Schmidt TS. Cost-efficient demand-pull policies for multi-purpose technologies – The case of stationary electricity storage. Applied Energy 2015;155:334–48.
[31] Müller UP, Schachler B, Scharf M, Bunke W-D, Günther S, Bartels J et al. Integrated Techno-Economic Power System Planning of Transmission and Distribution Grids. Energies 2019;12(11):2091.
[32] BMU. Kurzinformation Elektromobilität bzgl. Strom- und Ressourcenbedarf. [November 09, 2021]; Available from: https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Verkehr/emob_strom_ressourcen_bf.pdf.
[33] VBEW. Doppelter Haushaltsstromverbrauch mit Elektroauto. [November 09, 2021]; Available from: https://www.vbew.de/energie/presseinfos-energie/news/doppelter-haushaltsstromverbrauch-mit-elektroauto.
[34] Kucevic D, Semmelmann L, Collath N, Jossen A, Hesse H. Peak Shaving with Battery Energy Storage Systems in Distribution Grids: A Novel Approach to Reduce Local and Global Peak Loads. Electricity 2021;2(4):573–89.