Grid Boosters as innovative solution to optimize power grids

How Storage as Transmission Assets increase the utilization of transmission lines in EHV grids

Final report

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Fluence

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consentec

Who are Consentec and Fluence?

Consentec is a Germany-based boutique consultancy with outstanding knowledge on technical and economic questions in power systems. Congestion management has always been in the focus of our work. The original idea for grid booster batteries is closely linked to previous work by Consentec for German TSOs and government agencies. Consentec advised the German Ministry on Economic Affairs (now BMWK, formerly BMWi) in the initial discussion process on the grid booster concept, including modelling exercises and an initial cost-benefit analysis. Hence, Consentec is deeply familiar with the grid booster concepts and related chances and challenges.

Fluence Energy, Inc. (Nasdaq: FLNC) is a global market leader in energy storage products and services, and cloud-based software for renewables and storage. With a presence in over 40 markets globally, Fluence provides an ecosystem of offerings to drive the clean energy transition, including modular, scalable energy storage products, comprehensive service offerings, and the Fluence IQ Platform, which delivers AI-enabled SaaS products for managing and optimizing renewables and storage from any provider. The Company is transforming the way we power our world by helping customers create more resilient and sustainable electric grids. In October 2022, TransnetBW GmbH, a German Transmission System Operators (TSO), announced they had chosen Fluence as a 250 MW battery-based energy storage supplier for a grid Booster project in Kupferzell, at the time the world's largest Storage-As-Transmission-Asset project owned by a TSO. It follows the award of a 200 MW energy storage portfolio to Fluence by EPOS-G, the owner of Litgrid, the Lithuanian TSO, in late 2021.

Abstract

Storage-As-Transmission-Assets (SATA) can support the transformation of power systems around the world in a cost-effective manner by increasing transmission capacity of existing and new build transmission networks. In this study we describe the concept and operational principle behind the grid booster battery projects in Germany. These assets with a joint size of 450 MW are currently implemented by German transmission grid operators as part of the 2019 grid development plan. Once operational, they will allow a higher utilization of the existing grids resulting in considerably reduced congestion management requirements, especially renewable curtailment in Germany, thereby increasing the efficiency of the power network and saving costs to consumers.

As SATA solutions start to emerge in power grids around the globe, it is important to explain the underlying operational principle and economics behind their deployment. Sharing these insights will enable the transfer of such innovative grid technology solutions to other markets around the world.

This study outlines:

- The innovative concept of using grid booster batteries to increase utilization of power grids. In detail, the new underlying operational philosophy of reactive grid operation, which significantly reduces spare transmission line capacity. Under this operational philosophy, grid security requirements (known as (n-1) criterion) are transferred to the grid booster batteries. This is enabled by a change in the operational paradigm from one of preventive congestion management, which reduces transmission line capacity, to one of reactive grid operation, which (partially) frees previously withheld transmission line capacity.
- The economic benefits realized by using grid booster batteries by reducing preventive congestion management requirements and renewable curtailment, thereby lowering grid fees, and enabling more low-cost renewable generation to come online.
- A detailed case-study of the economic evaluation and cost-benefit analysis of the grid booster batteries in Germany. This serves as an example for markets with a **zonal price system and cost-based congestion management**. The assessment of deploying grid booster discloses effects that will decrease grid tariffs and increase socio-economic welfare as cheaper resources, including renewable generation, can be used for electricity supply.
- The economic evaluation principles of grid booster batteries in markets with **price-based congestion management, such as local marginal pricing (LMP)** in parts of the USA. In systems with local marginal pricing grid booster batteries have a similar impact as conventional grid reinforcements. Yet they are a cheaper solution have fewer barriers for permitting and can be realizes faster.
- With respect to **cross-zonal congestions in markets with different price** zones like Italy or Scandinavia, or in respect to different price zones within Europe, grid booster batteries could accompany grid expansion measures and, having much lower realization periods, contribute to rapidly achieving benefits from higher cross-border transmission capacities.
- The economic evaluation principles behind grid booster batteries in **markets with vertically integrated utilities** like the Southeast of the US, Western Australia, or many developing countries. In these markets grid booster batteries could result in lower costs for system development and operation, outweighing the installation costs for the boosters themselves and ultimately lead to lower prices for consumers.

Abbreviations

AC	Alternating Current
EHV	Extra-High Voltage
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
GDP	Grid Development Plan
HVDC	High-Voltage Direct Current
LMP	Locational Marginal Prices
NRA	National Regulatory Authority
PATL	Permanently Admissible Transmission Loading
RES	Renewable Energy Sources
SATA	Storage-As-Transmission-Asset
SIPS	System Protection Integrity Scheme
TATL	Temporarily Admissible Transmission Loading
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan

1 The grid investment challenge and the role of smart technologies

The demand for long-distance transmission of electrical energy has increased significantly over the past decades and is expected to increase over the next decades. This trend is driven by the rapidly growing share of renewable energy power generation which is often installed at long distances from load centers as well as the increasing desire for domestic and cross-border electricity exchange to reduce the costs of electricity and foster security of supply.

It is widely recognized that transmission systems need reinforcement and expansion to cope with increasing demand. This is also reflected in European (TYNDP) and national network development plans. However, the expansion of grid capacity has for some time been falling behind what is needed to achieve ambitious targets for the transformation of the electricity system (an inevitable component of the EU Green Deal). This includes grid expansion in the offshore environment where no grids have previously existed indeed. Offshore wind is growing in prominence and will require new grids to bring this power back to land. The European Commission estimates that EUR 800 billion must be invested in offshore renewable technology by 2050. Of this, it expects two thirds of the investments will be associated with grid infrastructure and one third for offshore generation assets. Annual investment in onshore and offshore grids in Europe need to double from EUR 30 billion per year to above EUR 60 billion per year in this decade, and then increase further after 2030, the European Commission believes. The enormous cost of proposed investments in grid expansion as well as broader public acceptance issues weigh heavily in the minds of regulatory authorities and policy makers.

While it is widely recognized that grid expansion will be required, reducing congestion on already existing infrastructure can play a crucial role in accelerating and reducing the overall cost of the energy transition. Whereas most grid expansion projects continue to rely on traditional technologies, such as installing new lines or increasing the capacity of existing lines by installing additional circuits, the potential for proven smart grid technologies to optimize the operation of transmission systems has been widely recognized for some years now. Germany, Austria, and Switzerland, for example, require TSOs to consider optimization and reinforcement measures before planning new lines. Under the “NOVA principle” regulators have approved adjustment of the capacity ratings for new and existing lines based on ambient temperature as well as the use of phase-shifting transformers for load-flow control.

Given the scale of the challenge of electrification and the change of the system, all solutions, i.e., more lines, reinforced lines but also the use of technologies for optimization are needed in combination. Large scale batteries e.g., operated as grid boosters represent one of several solutions to allow for a higher utilization of the existing transmission system, to reduce costs in particular related to congestion management and enhance both operational flexibility and reliability for TSOs.

The application of large-scale batteries as Storage-as-Transmission-Assets (SATA) is not only limited to the German transmission grid. For example, in the UK grid booster applications are tendered in the so-called Constraint Management Pathfinder project to reduce the need for new grid infrastructure[1]. In New South Wales (Australia) the Minister for Energy appointed the Network Operator in 2022 to carry out the Waratah Super Battery Project. his project that was awarded in late 2022 consists of a single 700 MW / 1.400 MWh battery that will be used under

[1] www.nationalgrideso.com/future-energy/projects/pathfinders/constraint-management/noa-constraint-management-pathfinder-phase-1

the System Protection Integrity Scheme (SIPS) to increase the transmission capacity of the existing network[2]. In Chile, a 2 x 500 MVA battery project introduced in Chile's 2021 expansion plan was approved in August of 2022 by a panel of experts and work on the projects is due to start from 2024.[3]

2 What are Grid Booster Batteries?

2.1 Secure Operation of Transmission Systems

There is no technical system, including power systems, which is 100% reliable. But especially for extra-high-voltage (EHV) transmission systems, which are the backbone of our electricity supply and responsible for the reliability of the power system in large areas or entire countries, robustness against unavoidable contingencies is a major design principle. This is operationalized by the so-called (n-1)-criterion for secure transmission system operation.

The criterion requires grid operators to operate transmission systems in a way that even with single contingencies no permanent violations of operational limits (like admissible transmission loadings or voltage corridors) will occur. Temporary violations of operational limits might be permitted, but even then, a propagation of a disturbances to system level, potentially resulting in cascading outages, a loss of system stability and blackouts must be prevented.

This requirement typically leads to situations where elements like lines and transformers in AC transmission systems are not fully utilized in normal system operation without contingencies, i.e., for most parts of the year. One reason for that is that load flows in a standard AC system cannot be actively controlled to achieve an even distribution of line loadings but will follow impedances, thus resulting in single lines being already fully loaded while other lines might have spare capacity which cannot be utilized effectively[4]. Another reason is that load flows which were carried by the failing network element before the occurrence of a contingency situation will then be redistributed according to Kirchhoff's Laws resulting in higher flows on the remaining network elements. In typical configurations with double circuit transmission lines a failure of the parallel circuit may well result in a 30% increase in line loading. To prevent a violation of operational limits in such scenario without having to apply additional measures, transmission lines in normal system operation are often operated with a loading that must not exceed roughly 70% of their thermal rating.

2.2 Reactive System Operation with Grid Booster Batteries

This is where the concept of reactive system operation steps in. With thermal rating being the binding operational limit for most transmission assets, there is actually no need for keeping line loading below the so-called permanently admissible transmission loading (PATL) immediately after a contingency situation being occurred. Instead, because of thermal inertia, a higher loading than PATL may be admissible for a limited time without endangering system security. This is why in addition to PATL there are also so-called temporarily admissible transmission loadings (TATL) defined for many transmission assets. If we assume that failures might result in an additional 30 percentage points of line loading, a typical time period for which a line operated at

[2] www.energy-storage.news/blackrock-acquired-developer-awarded-1-4gwh-super-battery-contract-in-new-south-wales/

[3] www.bnamericas.com/en/news/chile-panel-paves-way-for-including-us211mn-storage-project-in-2021-transmission-plan

[4] Special active devices like phase-shifting transformers or FACTS mainly serving to protect one or a few specific lines might also be used to achieve a more even distribution for load-flows and increase the actual transmission capacity within a given grid.

PATL before the failure could carry this additional current without endangering system security will typically be in the range of several tens of seconds to a single-digit number of minutes.[5]

Imagine now a scenario where a reliable process is available to relieve this temporarily overloaded line and reduce load flows to a level below/at the PATL within the time period mentioned above.[6] In such a scenario, other than today, where transmission lines only have a normal loading of below roughly 70%, in normal operation the line could be operated at full capacity without endangering system security. In particular, such an operational concept would still fulfil the (n-1)-criterion.

We propose to call such an operational concept reactive system operation because line loading is not reduced preventively to accommodate for a range of potential contingencies[7]. Instead, in the case of a contingency, network operators react with targeted measures to maintain system security. Figure 2.1 illustrates the basic principle of the concept.

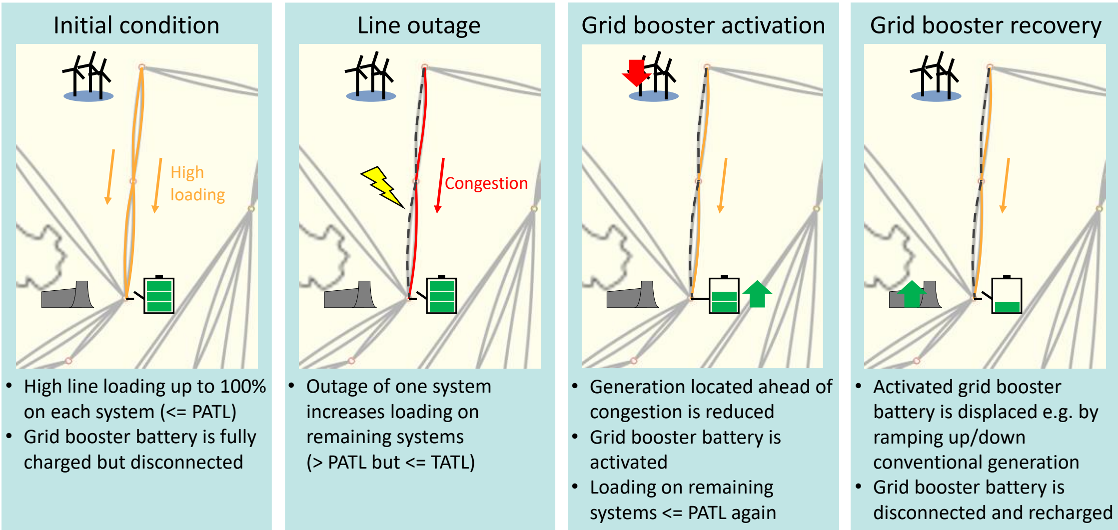

Figure 2.1: Basic principle of the reactive grid operation concept (schematic illustration)

The idea of reactive system operation is not new to power systems. For decades now, so called special protection schemes have been in place e.g., in European transmission systems where specific switching operations where automatically initiated in the case of a failure of a transmission asset to let the system converge into a new stable steady-state without violating of security limits.

Such special protection schemes have been typically limited, however, to special, often radial topologies where consequences of a failure of a single grid element are obvious as well as locally limited and where countermeasures like shedding of certain industrial loads are reliably

[5] https://www.meteodat.ch/pdf/Leitererwaermung.pdf

[6] Theoretically, reactive system operation could also be conceived in a way where relief measures are applied and effective even before fault clearance (e.g. within 150 msec after a failure occurs). Whereas such rapid reaction is much more ambitious than the concept described above, and not necessary as long as thermal loading of network elements is the primarily relevant operational security limit, it would allow to allow reactive system operation to be applied even where other operational limits like angular stability become binding.

[7] Other discussants have called identical approaches “curative system operation” It should be noted, though, that this should not be mixed with the term “curative congestion management” which is often used for remedial actions which aim at resolving foreseeable breaches of operational limits close to real-time (i.e., after market), but are nevertheless preventive in a way that they do not react to the actual occurrence of contingencies.

available and easy to control. Organizing remedial actions to quickly relieve overloaded network elements within an interconnected system, instead, would have required to ramp up and down several generators with limited technical capabilities and often not directly controlled by TSO control centers. Under most circumstances, at least, this was simply considered not to be feasible within the available time period for such operations.

This might change in the future with power systems being digitized and where TSOs might be no longer reliant on conventional plant technology but might have access to vast numbers of dispersed (supply- and demand-side) resources which could change their behavior within sufficiently short times to reliably manage temporary overloads after contingencies have occurred. But today, this option is still far from reality.

Large-scale batteries, however, represent an available technology and can change their injection to the grid or offtake from the grid more or less instantaneously. They can be deployed within short time frames close to existing transmission substations and can also provide additional ancillary services like reactive power next to storage capability. With these properties, batteries used as transmission assets and directly controlled by transmission system operators are an ideal solution to apply concepts for reactive system operation and allow a higher utilization of existing transmission assets.

This is the main idea of the grid booster pilot projects in Germany which were adopted by the National Regulatory Authority (NRA) Bundesnetzagentur as part of the national grid development plans and will be realized over the coming years. The German transmission system is suffering from structural congestion between the northern and eastern parts of the country where major parts of the RES generation, especially onshore wind, are located, and the industrial load centers being in the West and South of Germany. Currently three large-scale grid booster battery projects, two in the South and one in the North, with a total capacity of 450 MW are planned and shall be realized until 2025.

Congestion management measures with ramping down cheap (often RES) generation in the North and ramping up more expensive conventional generation in the South are daily business for TSOs, resulting in annual congestion management costs of almost EUR2.3 bn in 2021. Although cost figures for 2022 are not available yet, these costs are very likely to significantly increase in the short-term mainly due to high gas prices caused by the energy crisis as a consequence of the Russian invasion of Ukraine as already the German government.

Significant grid expansion is underway (including three North-South HVDC connections with an installed transmission capacity of 10 GW in total) but has been stuck in permitting procedures for many years. The grid booster batteries will be used for reactive system operation allowing for a higher utilization of transmission lines in normal operation. In the case of a contingency occurring, the resulting overload will be relieved within seconds to minutes by balance-neutral charging of grid booster batteries in the North and discharging those in the South. Alternative to charging batteries in the North, offshore wind farms directly connected to the transmission system could also be automatically shed. The grid booster batteries will have a storage capacity allowing them to operate at full capability for an hour. This will give TSOs sufficient time to activate slower, but more enduring measures like ramping up or down of conventional generation to replace the grid booster batteries. Figure 2.2 introduces a comparison of principle properties between current redispatch and reactive grid operation.

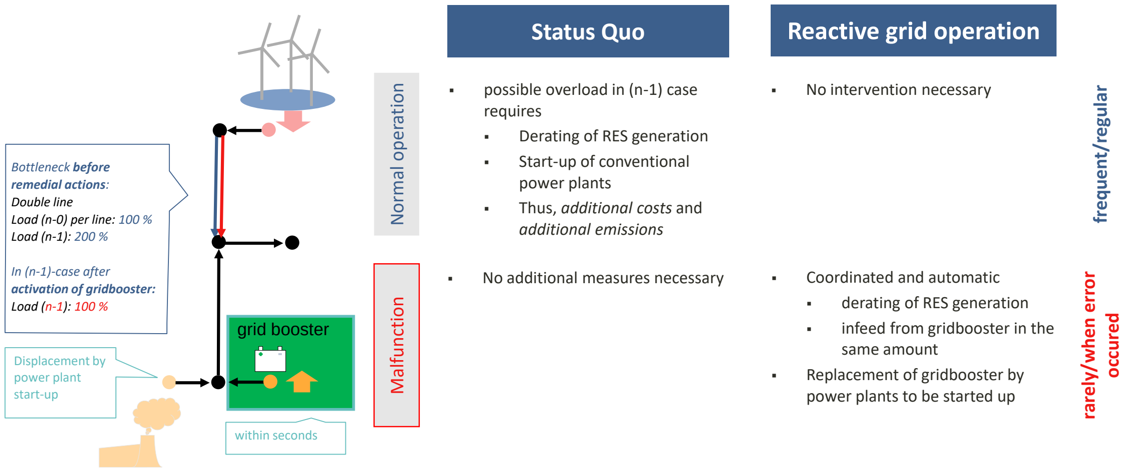

Figure 2.2: Comparison of current redispatch and reactive grid operation (basic principle)

To maximize the availability of the grid boosters their storage capacity will, at least for the time being, be exclusively used by TSOs and not sold on electricity markets. After each activation, batteries will be discharged (in the North) or charged (in the South) and remain in that state of charge during normal system operation.

The currently planned grid booster projects are meant as pilot projects to gain experience with the large-scale application of reactive system operation. Given a positive evaluation, additional projects can be expected in the future.

3 Grid Booster Batteries in Different Regulatory Environment

Physically, grid booster batteries increase the capacity of AC transmission systems because they reduce the share of physical capacity which cannot be used in normal operation but is kept as a reserve for contingency situations. Depending on the legal and regulatory environment under which grid boosters are operated, there are differences, however, how the additional physical capacity translates into economic benefits.

In the following this will be outlined for cost-based congestion management in zonal market systems, for price-based congestion management in locational marginal pricing systems and for cross-zonal congestion, as well as for vertically integrated utilities.

3.1 Cost-Based Congestion Management

The grid booster idea was developed in Germany which is part of the EU Internal Electricity Market. One main institutional characteristic of this market is the zonal market model. The market is divided into bidding zones which often (but not exclusively) follow borders of nation states.[8] Within bidding zones, electricity trading is not restricted by transmission capacity constraints. This can (and in the case of Germany often does) result in after-market congestion, i.e., agreed exchanges which cannot be realized without endangering system security.

To maintain system security, TSOs must apply curative (i.e., after market) congestion management measures based on the market outcome. The usual remedial actions include non-costly measures like switching operations or changing tap positions of phase-shifting transformers and,

[8] Sweden, Italy and Norway, with the latter not being an EU, but an EFTA member and as such applying the rules of the EU Internal Market, are divided into more than one bidding zone, whereas Germany and Luxembourg have a joint bidding zone.

above all, coordinated adjustments to market-based dispatch, in Germany typically called re-dispatch. With re-dispatch, in-the-market generators which contribute to the congestion are ramped down whereas out-of-market generators relieving the congestion are ramped up. In Germany, the participation in this scheme is mandatory for generators with a capacity of 100 kW and above. For their participation and activation, generators receive a cost-based compensation (the level of which is estimated based on previously agreed general rules). This means that generators which are ramped down but – as a prerequisite to being ramped down - sold their electricity production on the market beforehand will get a physical compensation for the electricity not produced to be able to fulfil their contractual obligations for delivery of electricity but will have to reimburse any avoided costs due to the non-production, mainly fuel costs. In contrast, generators which are ramped up will financially be compensated with the costs for the additional electricity production but will have to deliver the produced electricity to the TSO (who uses it to physically compensate the ramped down generator). Typically, the avoided costs reimbursed by the ramped down unit (which was in the market, i.e., typically had variable costs at or below market price level) will be lower than the compensation for the ramped-up unit (which typically was out-of-market because of variable costs above market price level).

From an economics perspective, this redispatch means that more expensive resources have to be used to maintain a secure electricity supply, hence socio-economic welfare is reduced by the (integral) difference of variable costs of ramped down and ramped up units. Operationally, these costs are first borne by TSOs and then socialized via grid tariffs.[9] In 2021, the total costs in Germany amounted to almost EUR2.3bn. In addition, redispatch often means curtailment of renewable generation, resulting in a situation where green energy which could be produced with existing generators cannot be used and actual costs of renewable generators per MWh produced will be higher than necessary. In 2021, the amount of renewable generation affected 5.8 TWh (almost 3% of total RES generation). Compensations which had to be paid to renewable generators despite being curtailed amounted to EUR800m.

With the grid boosters being deployed, the transmission capacity of the system is increased. All other things equal, this will result in lower volumes of necessary redispatch and, therefore, lower costs for congestion management. The following figures show exemplary results for a sample application in the German system considering different assumptions regarding installed capacities of grid booster batteries in the South and units to decrease generation or increase load in the North, respectively.[10]

[9] In reality, redispatch costs accrued by TSOs not only cover actual changes in costs of electricity production, but also include economic rents (e.g. compensation for sunk costs and lost profits/subsidies). Nevertheless, the major portion of redispatch costs is driven by differences in variable cost of units which have to change their electricity production to maintain system security.

[10] The installed capacity of grid booster pilot projects accounts to 900 MW for generation increase and 400 MW for load increase according to the TSOs' draft of the GDP 2030 (2019).

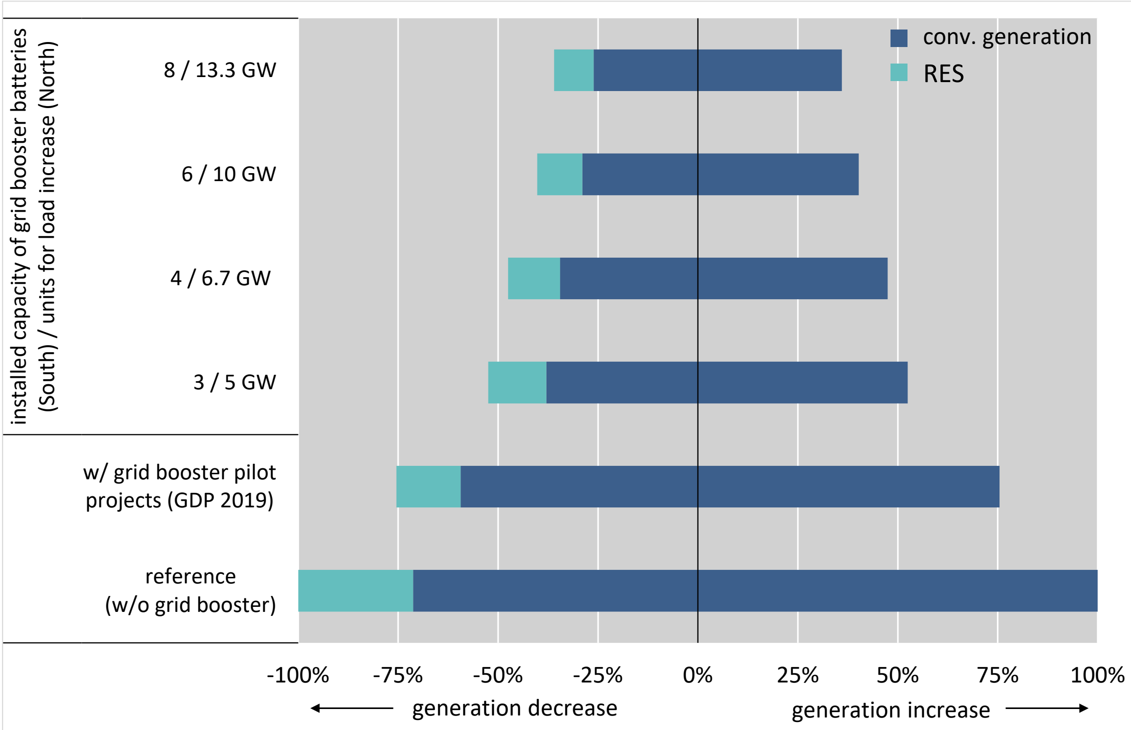

Figure 3.1: Necessary volume of preventive redispatch in Germany for different assumptions of installed grid booster capacities (sample application)

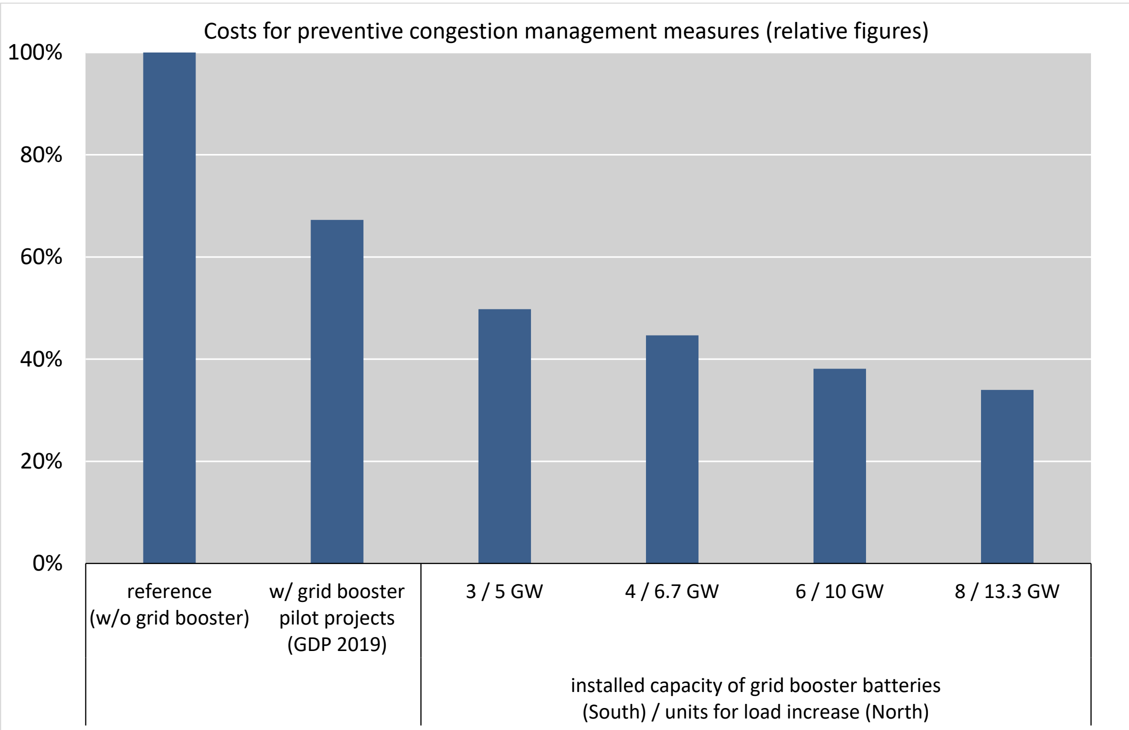

Figure 3.2: Costs for preventive congestion management measures in Germany for different assumptions of installed grid booster capacities (sample application)

The figures highlight that in general increasing grid booster capacity creates additional benefit regarding necessary redispatch volumes and congestion management costs, but the marginal benefit decreases with increasing capacity.

These effects will decrease grid tariffs and increase socio-economic welfare because cheaper resources can be used for electricity supply. In 2021, in their revised version of the network development plan, German TSOs estimated the necessary time period for cost recovery of grid booster batteries to be 11 and 13 years, respectively. Such estimations obviously depend on assumptions on development of transmission demand and commissioning of grid expansion projects. But finally, German NRA Bundesnetzagentur approved the projects confirming that even with pessimistic assumptions (including the pilot character which will not result in realizing full potential benefits) these projects will recover their investment costs, at least, within their expected minimum technical lifetime.

Other than mandatory participation with cost-based compensation, other arrangements for curative congestion management with more voluntary participation exist in other European countries. Regardless of pros and cons of mandatory vs. voluntary participation, with either arrangement, grid booster batteries will have similar effects on socio-economic welfare and congestion management costs.

As the main benefit of grid boosters in Germany is the reduction or even elimination of existing congestions by allowing a higher utilization of existing network infrastructure, the deployment of grid boosters can similarly reduce proactively future congestion that is expected due to changes in the generation and load profile and structure. In these cases, grid boosters can be seen as an alternative cost to traditional grid reinforcements that would become necessary to reduce future congestion.

3.2 Price-Based Congestion Management

3.2.1 Locational Marginal Pricing

In contrast to zonal market arrangements with curative congestion management, many liberalized electricity markets in the US and other parts of the world like Singapore apply a model of price-based preventive congestion management called locational marginal pricing (LMP) or nodal pricing.

With LMP, there is an integrated and centralized matching and dispatch mechanism. Transmission constraints are known to the matching algorithm on a node/line level and the market is cleared with the objective function of maximizing welfare subject to the above-mentioned transmission constraints. Hence, other than in zonal markets, typically there will be no after-market congestion. Instead, in case transmission constraints become binding, prices diverge and nodes in the surplus area clear at lower prices than nodes in the deficit area.

As a consequence, there are no (or very little) explicit congestion management costs which would have to be socialized via grid tariffs or similar mechanisms. Nevertheless, if transmission constraints become binding this will affect market outcome and result in a dispatch where relatively cheaper units cannot run because their electricity production could not be transported to the consumers and relatively more expensive units will be dispatched to relieve/not worsen the congestion. Hence, also with LMP and without explicit congestion management costs, socio-economic welfare is adversely affected by limited transmission capacity. This loss of socio-economic welfare results in higher prices and/or lower rents for market participants.

In such a setting, grid booster batteries which would increase the physical transmission capacity of the system would mean that transmission constraints for the matching algorithm could be relaxed, resulting in more cheap energy production which could be dispatched and less expensive energy production which needs to be dispatched. Consequently, as in zonal market arrangements, there will be an increase in socio-economic welfare due to grid booster batteries. This increase in welfare will be realized by market participants in terms of lower price peaks and higher rents to be earned.

The case for grid booster batteries in an LMP environment might be less intuitive than in a zonal environment where costs for TSOs are directly compensated by cost reductions in congestion management, but it is not less substantial. Instead, in an LMP system, grid booster batteries have a similar impact as conventional grid reinforcements but come at much lower price point and with fewer barriers for permitting and realization.

As in zonal pricing systems, grid planning in LMP electricity markets is based on the economic and benefit assessment of proposed transmission upgrades. Grid upgrades will receive regulatory approval and hence inclusion in transmission cost recovery via grid fees if they can show a positive cost-benefit-ratio. All markets with regulatory approval have established methodologies for transmission planning processes. Storage-As-Transmission-Assets like the grid booster need to be integrated into those methodologies based on their investment and operation costs as well as the socio-economic benefit the assets create[11]. Different asset lifetime for battery assets, as well as faster deployment and therefore relieve of congested grid nodes are to be considered. If such methodologies are implemented, grid boosters could be deployed in LMP electricity markets on their economic merits.

3.2.2 Cross-Zonal Congestion

Similarly, in a zonal system like the European Internal Electricity Market, where prices do not differ between nodes, but between bidding zones, grid booster batteries could be used to increase cross border transmission capacity and unlock social benefits which would otherwise require high-effort cross-border transmission expansion.

There is little doubt that additional cross-zonal transmission capacity would bring substantial socio-economic benefit. This was also recently confirmed by the so called “Power System Needs Study” which was performed by ENTSO-E, the European Network of Transmission System Operators. The study concludes that there is significant need for cross-border grid infrastructure in 2030 as well as in 2040 and that the reinforcement projects considered in the study would deliver about 70% of the maximum achievable benefits. Avoiding transmission expansion at disproportionately high costs by applying solutions based on alternative technologies might further increase the socio-economic benefit.

Obviously, grid booster batteries are no full substitute for normal grid expansion but could accompany such measures and, having much lower realization periods, contribute to rapidly achieving benefits from higher cross-border transmission capacities.

Therefore, independent from being applied within LMP or zonal systems, all financing channels typically used for incentivization and cost recovery of transmission expansion projects between price zones, should also be open for efficient grid booster batteries.

3.3 Vertically Integrated Utilities

The third possible regulatory environment where the deployment of grid booster batteries could be considered are vertically integrated utilities which typically cover all or at least several stages

[11] A recent discussion on problems in considering Energy Storage as Transmission Assets in planning processes in the US can be found here: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-32196.pdf

of the value chain ranging from electricity production over transmission and distribution to electricity supply. Examples for such environments are the Southeast of the US which largely retains the model of vertical integration, Western Australia as well as electricity systems in many developing countries.

Other than in liberalized electricity markets, with vertical integration there is no coordination problem between market participants and grid operators for grid planning and operation. With one single entity responsible for grid operation and dispatch, there is no need for an institutionalized preventive or curative congestion management. Instead, system planning as well as dispatch will take into account the relevant transmission constraints in system development, which could result in grid expansion to overcome transmission constraints as well as in generators being located at grid-friendly sites or resources like RES not totally explored because of transmission limits. Additionally, vertically integrated utilities will continuously arrange generator dispatch in a way that transmission constraints are obeyed.

Hence, in a vertically integrated environment, too, binding transmission limits will increase the costs for a reliable electricity supply. And as those costs will typically be passed on to consumers, they will pay for those transmission constraints with higher electricity prices.

The installation of grid booster batteries in such a system could positively impact system costs in various ways. If there are binding transmission constraints in the existing system those constraints will be relieved, and the dispatch could be adjusted to satisfy demand for electricity at lower costs. Even if there are no binding transmission constraints in operation because of a perfect coordination between generation and transmission planning, grid booster batteries could play a role when changing supply and demand patterns require an adaptation of the system. Here, grid booster batteries could be used as a cheap complement or substitute to more expensive conventional grid expansion measures.

In both cases, grid booster batteries could result in lower costs for system development and operation, outweighing the installation costs for the boosters themselves. In a regulated cost+-environment being typically for vertically integrated utilities this will result in lower prices for consumers.

Regulatory agencies would, however, have to set up appropriate incentive schemes to ensure that more efficient, less capital-intensive technologies like grid booster batteries are deployed instead of conventional grid expansion measures, where beneficial.

3.4 Overview

Regulatory Environment	Impact	Immediate benefit for	Benefits for consumers via	Incentive/cost recovery for grid operators necessary?
Zonal	Reduction of congestion management costs	Grid operators	Reduced network tariffs	Depends on regulatory model (TOTEX vs CAPEX regulation)
LMP	Price convergence of nodes	Grid users	Lower costs for electricity supply (distributional effects might vary)	Yes, similar to conventional grid expansion
Cross-zonal	Price convergence of zones	Grid users	Lower costs for electricity supply (distributional effects might vary)	Yes, similar to conventional grid expansion
Vertical integration	Reduction of total system costs	Vertically integrated utility	Reduced regulated tariffs	Yes, conventional grid expansion might be preferred by utilities in pure cost+ regime