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ENERGY STORAGE (M KINTNER-MEYER, SECTION EDITOR)

Review of Stationary Energy Storage Systems Applications, Their Placement, and Techno-Economic Potential

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Abstract

Purpose of Review This review paper attempts to give a general overview on the BESS applications that demonstrate a high potential in the past few years, identifying most relevant operators — or providers — with the corresponding placement for such. Together with a description of value proposition schemes, observed trends, and research fields, a collection of relevant project references is gathered.

Recent Findings Many publications and communications try to describe the services that battery energy storage systems can provide to each of the stakeholders, even though they might greatly differ based on national regulatory frameworks. The actual most relevant 6 applications in the view of the authors are described in more detail.

Summary In this paper, there has been pointed special attention on the BESS opportunities for each operator and their corresponding potential on revenue stacking. Additionally, the most important identified scientific papers for the 6 most important applications in the view of the authors are presented.

Keywords BESS applications · Revenue stacking · BESS placement · Upgrade deferral · Energy transition · Review paper

Introduction

The progressive and increasing integration of intermittent renewable energy sources (RES), as the foundation for the so-called energy transition, results in challenges for energy management and the stability of the power systems. Pressure on electricity systems further increases due to the electrification of other emission intensive sectors, such as transportation and heating, driven by the so-called sector coupling [1]. To successfully achieve the next step of the energy transition, additional grid supporting components and markets are needed, to properly balance the grid while less conventional power plants are available.

Although various flexibility options are considered for these tasks, battery energy storage systems (BESS) are currently one of the most promising candidates to fill this gap. Technically, these systems are characterized by the fact that they can provide a large amount of energy very quickly and with high efficiencies. Meanwhile, safety, reliability, and lifetime have reached a considerable level and, at the same time, costs have dropped significantly [2].

We are in a stage in which storage systems are increasingly being implemented to take over tasks that would not have been economically feasible a short time ago. Therefore, many investors are currently ready to invest in these applications and are looking for new areas in which storage systems can be prosperous business opportunity. Unfortunately, regulatory hurdles still exist in many countries, because of the difficulties to identify the role of energy storage within the traditional power system structure of generation, transmission/distribution, and consumption.

Several publications are already available that try to categorize the large variety of applications that can be provided by BESS to customers and to transmission/distribution grids [3–5]. From the authors' point of view, the following three publications should be highlighted:

- RMI, 2015 [6]: 13 main applications are identified, and revenue stacking possibilities are described, especially for customer-site collocated BESS

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- DNV-GL, 2017 [7]: recommended practice guide for grid-connected storage systems, differentiating 20 possible applications
- EASE, 2020 [8•]: giving definitions for 36 current and future energy storage applications

In this paper, the authors review a number of relevant studies for most of the possible applications, together with a list of representative projects, while adding our valuation of the techno-economic potential of each of the applications for different operators (service providers). The review, which is sorted in Table 1, follows the service structure proposed by EASE [8•]. It does not aim to be fully complete, but rather include a focused overview of the most relevant references and use-cases. In this table, the columns show the possible providers/operators of such an application, together with the corresponding location and grid layer. The rows show the possible beneficiaries for each application, while cell colors describe the techno-economic potential of each application estimated by the authors. The color coding is shown in the legend of Table 1.

It is worth mentioning that most of the presented applications can potentially be delivered by stationary BESS as well as electric vehicles (V2X : Vehicle2X (Vehicle-to-grid/building/home)), which is undoubtedly one of the most promising segments for the next decade.

As shown in Table 1, a high variety of different applications are possible for BESS. Thereby current regulatory frameworks — besides technical and economic criteria — play a major role in the deployment of BESS and can be identified as one of the main barriers for addressing the huge market potentials. Taking these boundary conditions into account, the following section focuses on six applications, which are currently of high relevance with respect to the authors' point of view.

This view on the selected applications has followed the steps to first introduce them, investigate on location specific criteria, and finally provide insights on market size as well as suitable technologies. Each application will be supplemented with some project figures and examples (Fig. 1).

Self-consumption

Several energy market studies [1, 61, 62] identify that the main use-case for stationary battery storage until at least 2030 is going to be related to residential and commercial and industrial (C&I) storage systems providing customer energy time-shift for increased self-sufficiency or for reducing peak demand charges. This segment is expected to achieve more than 100 GWh by 2030.

Photovoltaics (PV) self-consumption (SC) and the adoption of BESS is currently allowed in the vast majority of the world's countries (with defined technical connection rules), but there are many and very different approaches to its economic regulations. A common regulatory issue, which is addressed, e.g., in G. Masson et al. and Owen Zinaman et al. [63, 64], is the so-called *double taxation*, which forces battery operators to pay network charges and electricity taxes twice when charging — considering the battery as consumer — and when discharging — considering the battery as a generation plant.

This situation is observed especially in countries with high taxation, such as Germany with their EEG levy, still is an undue burden for investors, forcing them to retend their project ideas.

The reasons behind these optimistic forecasts are both technical and economic. On the one hand, behind-the-meter (BTM) battery storage adoption is inevitable to untap the full potential of decentralized energy production and foster the energy transition, by enabling reduced transport and distribution capacity needs, potentially decreasing distribution losses and/or increasing supply security [54]. On the other hand, the economic motivation of battery storage for SC is related to the gap between the price paid for excess power and the electricity billing price, a gap that tends to increase in most of the countries, and that already is comparable with a rapidly and constantly decreasing levelized cost of storage [65, 66].

In actuality, good examples of mature self-consumption markets are in South Korea [67] and Germany [68], where the market pull with favorable economic and regulatory conditions has led to a market diffusion over the past few years. A huge increase is also expected in the next 5 years in other countries such as China, USA, Australia, Japan, or the UK.

In Germany, a total installed capacity of about 1 GWh home storage systems has been reached, with more than 180,000 household installations in 2020 [69]. The market was financially fostered by the incentives and credit program, from 2013 to 2018, and pushed by early adopters that were driven mostly by endogenous factors, like private contribution to the energy transition, or high technical confidence and social acceptance [70, 71•].

Storage systems, from a technical point of view, are more efficient when placed as district storage units within the low-voltage (LV) distribution grid, enabling more PV penetration at household level, and, e.g., enabling more effective grid services such as voltage control [23, 54–56]. Although shared storage installations for SC are not viable in many countries due to regulative constraints and inevitable double imposition of network taxes and levies [55], some utilities have investigated such applications, e.g., in German research projects [57–59].

Nonetheless, the BTM segment in Germany is moving quickly towards the opposite direction, namely "virtual aggregation," which is enabled through smart information and communications technology, facilitating a coordinated action to system

Table 1 Overview of the most important applications that can be realized with the help of BESS based on the categories of the European Association for Storage of Energy [8•].

(Beneficiary, Customer)	BESS Applications:	Where do you place it? (Provider)						
		Consumer		Grid / Distribution				Bulk Generation
		Low voltage		Medium Voltage			High Voltage	
	Operation level / Place	Local		Regional / Municipal			National	
	Operator	Residential	C&I	3rd Party	Utility	DSO*	TSO*	Utility
Generation support	Arbitrage			▒ [9, 10]	█ [9, 10]			█ [11]
	System Electric Supply capacity		[12]	█ [13]	█ [13]			▒ [13]
	Support Conv. Generation			▒	▒			█
	Seasonal Arbitrage			░	░			▒ [14]
	Ancillary Services RES Support	▒	▒ [15–17]	▒ [15–17]	▒ [15–18]	[15–17]	[15–17]	▒ [11, 15–17, 19]
	Capacity Firming		░	▒	▒			▒
	RES Curtailment Minimization	▒	▒	█ [20–22]	▒ [20–23]			█ [21]
Transmission	*Transmission Grid upgrade deferral*			▒			█ [24–26]	▒ [24–26]
	Contingency Grid Support					░	█ [27]	▒ [27]
	Transmission Support	[28]	[28]			░ [29]	▒ [29, 30]	
	Angular Stability					░	▒	█
	Reactive Power Compensation					░	█	█
	Cross Sectoral Storage	░ [31]	░ [31]	█ [31]	▒ [32]			█ [32]
	Power Oscillation Damping (POD)						▒	
Distribution	*Distribution Grid upgrade deferral*	░ [33, 34]	█ [33, 34]	▒	█ [33–35]	█ [33–35]		
	Contingency Grid Support	▒	▒	█ [23]	█ [23, 29]	█ [29]		
	Dynamic Local Voltage Control	▒	▒	█ [18]	█ [18, 29]	█ [18, 29]		
	Intentional Islanding	▒	█ [36]	█	▒			
	Reactive Power Compensation	▒	█ [33]	█ [37]	█ [23, 33, 37]	█ [33, 37]		
	Cross Sectoral Storage	░	▒	█ [32]	█ [32]			
Ancillary Services	*Frequency Containment Reserve*	░ [28]	▒ [10, 28, 38]	█ [28]	█ [39–44]	▒ [45]	░ [30]	█ [11, 19, 43]
	Automatic Frequency Restoration Reserve	░ [12]	▒	█	█ [43, 44]	▒ [45]	░ [30]	█ [19, 43]
	Manual Frequency Restoration Reserve		░	▒	▒ [44]	░	░	▒ [19]
	Replacement Reserve							
	Load Following			▒	▒	▒ [46]		
	Frequency Stability (Weak grids)	░	░	▒	▒ [47]	▒		
	Black Start			░	░ [27]			▒ [27]
	Voltage Support	░ [12]	░	▒	▒ [18]	█ [46]	█ [30]	▒
	New Ancillary Services	░	░ [17, 48]	▒ [17, 48]	▒ [17, 44, 48]	█ [17, 48]	█ [17, 48]	▒ [17, 43, 48]
EMS / Customer Services	*End-User Peak-Shaving*	░	█ [10, 38, 49, 50]	█ [10]	░	[46]		
	Time-of-use / energy cost Mgmt.	█ [51]	█ [51]	▒				
	Energy Quality		█ [52, 53]	█ [52, 53]	█	▒		
	Maximizing Self- Production / Self-Consumption	█ [28, 54–56]	█	█ [28, 55, 57, 58]	░ [54–56, 59]	[46]		
	Continuity of Energy Supply / UPS	▒	█	█	▒			
	Limitation of upstream disturbances (Distribution)		█	▒	▒	░ [46]		
	Compensation of reactive power		█ [52, 53, 60]	▒ [52, 53]	▒ [52, 53]	░ [46]		

Color coding shows: no potential | ░ low potential | ▒ medium potential | █ high potential

*These operators are not authorized to operate BESS systems commercially in many countries. Nevertheless, the authors see the mentioned potential applications following the virtual power plant approach. A success story is, i.e., the pre-qualification in 2018 from energy storage company "Sonnen GmbH," which started as a manufacturer and provider of home-storage systems, later expanding the portfolio to become an electricity supply utility which offers virtual power plant services in frequency regulation (FCR and aFRR) and congestion management markets ("Redispatch 2.0") thanks to the cooperative control of the residential and C&I battery storage systems from their customers [28]. Thanks to the service provision by the BESS systems, end-customers can benefit from energy tariff reductions.

Peak Shaving

The design of power grids and power plant capacities is determined by the power peaks that occur over time. Even though load peaks occur rarely during the year, the entire transmission system and the power plant assets must be designed for this worst case scenario. Such power peaks can therefore considerably drive up the investment costs of the power system [72, 73].

There are different options to reduce these power peaks. For example, peak shaving (PS) can be achieved by direct load control, or so-called demand side management [73]. The power price, which is usually charged monthly, is not calculated in the same way by all electricity providers. As a rule, the highest measured power value at the electricity meter (usually a value averaged over 15 min) is used to determine the power price (demand charge). The tariff structure applied in each grid area depends on many factors, e.g., the composition of consumers in the grid area. In some grids, comparatively low capacity prices are charged, while in others, very high capacity prices are applied [4]. In addition, companies are assigned to different tariff structures based on several parameters. For instance, there is often a certain annual energy consumption threshold above which a capacity charge applies. In Germany, this value is set at 100 MWh [49]. Moreover, in some grid areas, lower capacity prices are charged if the so-called duration factor lies beneath or above certain thresholds [49]. The share of electricity costs that a company has to pay for the demand charges can be as high as 50% [73]. This shows the potential that can be achieved if the expensive peaks are shaved to lower values. Though it is important to keep in mind that the pricing structure of the electricity provider determines whether the usage of a BESS for PS is attractive or not [49].

The correct design and size of the BESS are of key importance. If the system is sized with a small capacity, this can lead to a lack of power available to absorb a peak and therefore the same power prices have to be paid as without storage [50, 72].

The installation of a BESS for PS as described above is limited to C&I companies that are forced to pay high demand charges to their electricity company. For Germany, R. Martins et al. [49] show that 33% of such type of companies will be able to achieve return on invest values of less than 5 years in the future.

In literature, one finds many interesting case studies for the PS application. N. Nasiriani et al. [74] present an article about the risks and benefits of PS in datacenters. G. Fitzgerald et al. [6] give an example of a hotel in San Francisco where PS is applied in combination with other applications to create a positive business model.

The PS application can in principle be combined with many other applications as stated in S. Englberger et al., F. Braeuer et al., and J. Engels [10••, 38, 75], and usually requires very few equivalent full cycles. An example for revenue stacking of PS with frequency containment reserve (FCR) is given by Y. Shi et al. [76]. A combination of PS and energy arbitrage is presented by C. Rahmann et al. [72].

Ancillary Services RES Support

The ancillary services (AS) for RES support application is assigned to the generation support section in Table 1, even though there is also a section specific to AS. This is because the storage facility used here does not provide this application on its own but rather enables connected RES to do so.

For the general definition, it can be said that the AS listed in Table 1 on the one hand serve to keep the frequency and voltage of the grid within a defined band and on the other

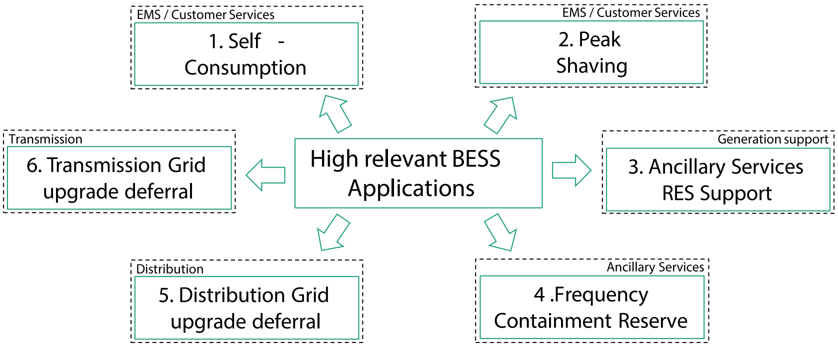

Fig. 1 Overview of high relevant BESS application for different categories of the European Association for Storage of Energy [8•]

hand support grid restoration in the event of a disturbance [77].

Traditionally, AS have been mainly provided by the synchronous generators (SG) that are part of the fossil fuel power plants. However, the increasing integration of RES strongly reduces those machines and thus creates the necessity to substitute the functionality of the SG. Nevertheless, the grid integration of RES not only requires additional AS, but also has the potential to provide AS to the grid. Regarding the ability to provide AS, RES technologies differ from each other to some extent. For example, wind turbines can provide a certain degree of synthetic inertia [15, 78], which is not possible for PV parks [16]. For the provision of some AS, the RES plant must therefore be additionally equipped with a storage system. For the provision of synthetic inertia, an appropriate fast-acting energy storage systems (ESS) such as a flywheel, supercapacitor, or battery can be used [16].

To be able to participate in the AS market at present (i.e., to provide AS to transmission system operators), a prequalification process is normally undertaken. In Germany, 57 companies were licensed in July 2020 [79]. The extent to which the market for AS is currently changing can also be seen from the availability of several suppliers which are able to provide their services with the help of virtual power plants (e.g., “Sonnen GmbH” and “Next Kraftwerke GmbH”).

However, even though certain AS are already provided today by RES power plants in combination with storage, there is still no market for many of the applications [48]. The process to redesign the existing AS products and create new ones is currently ongoing for many of the world’s countries, but still includes a wide range of technical decisions because of different proposals in research regarding the provision of inertial response and primary frequency control [48, 80].

With regard to the question of who the AS RES providers are, it can be stated that the AS are generally supplied by third-party providers, but also in part by the transmission system operators (TSO) and distribution system operators (DSO) themselves [17]. Regarding the classification in Table 1, however, it can probably be stated that the utilities at the medium-voltage (MV) and high-voltage (HV) level will remain the operators here. However, there will be increasing opportunities for storage systems integrated with large PV plants to participate in the AS market.

An example of such a system is the 50 MWh vanadium redox flow storage system that is combined with a 3.8 MWp PV-System to provide AS, presented by the German Energy Agency (dena) in S. Mischinger et al. [81].

Frequency Containment Reserve

As indicated in Table 1, FCR is one of the most relevant AS. As a result of the good match between service requirements and BESS capabilities, namely rapid response time and high ramp capabilities, BESS are in several investigations found to be one of the best candidates to fulfill the role of large rotary machines in frequency stabilization (in primary /FCR or secondary /aFRR FR markets) from a technical perspective [42]. For example, L. Thomée [44] finds that through power system simulations of the whole Nordic system, 540 MW of Frequency Controlled Disturbance Reserve (FCR-D) controller storage can provide the equivalent to 130 GW of kinetic energy.

As a result, BESS have, in the last few years, already taken over substantial market shares of existing frequency balancing markets, mostly operated by TSO.

To name some examples, over 700 MW BESS have been commissioned in Europe to provide services to the common frequency control reserve market set in 2017, making up 50% of the 1.4 GW market [82]. In the USA, FR has also been the main driver for large-scale BESS deployment. With a share of about 75% of installed capacity, grid-scale BESS installations increased from 350 MW in 2015 to 870 MW by end of 2018 [83]. Similar growth has been reported as well in China, where large-scale grid BESS for grid services (energy shift and frequency restoration) or FCR reached a market share of about 1/3 of total BESS installations, and witnessed a growth from 150 MW in 2015 to over 1700 MW in 2019 [84].

FCR has enabled the biggest large-scale BESS projects to date, e.g., the 250 MW BESS from “LS Power” in California (2020) [19], and the 200 MWh/150 MW Hornsdale Power Reserve, Australia (2017) [11], which has proven high-quality provision of FR services, as stated by market operator AEMO.

However, and although marginal costs for BESS to provide FR services are close to zero, the balancing market is shallow and might saturate in the foreseeable future, eventually stagnating the number of new large-scale front-of-the meter (FTM) BESS installations. This has already been seen in the common FCR European market, where due to the increased market competitivity and the good performance of BESS, market prices have fallen by about 40% from 2016 to 2019.

The re-design of FCR markets are allowing i.e. short-term tender procedures (e.g., European market shifted in 2020 to daily market with 4-h provision blocks for FCR, or enhanced markets such as fast frequency markets in the UK or Ireland). The participation of smaller or pooled storage groups, and separation of energy and power provision can further dynamize the FCR markets for BESS [10••, 42, 69, 85]. Otherwise, the implementation of more efficient control strategies, which is still a hot research topic, might allow efficiency increasing of FCR provision of FTM installations, e.g., using the regulatory degrees of freedom, or combining FCR with participation in wholesale markets [10••, 39, 40, 86].

Alternatively, the provision of FCR services might shift towards coordinated action of decentralized BESS, as the combination of FCR with BTM consumer-services can boost profitability of the BESS by up to 30–45% as compared to FCR-alone [10••]. Such revenue stacking can eventually increase the revenue of small, BTM BESS installations from households or from C&I customers, so that they can become even competitive with large-scale installations that can only capture bulk power services [38].

Distribution Grid Upgrade Deferral

Constantly increasing electrical energy consumption caused by the reduction of fossil fuels and corresponding electrification of the transport as well as the building and heating sector requires a constant reinforcement and expansion of grid infrastructure. Especially on the distribution level, there is a high requirement, induced by the transition towards a more decentralized energy system. Traditional distribution upgrade, which includes transformer and MV feeder line replacement, is considered a capital (CAPEX) intensive process. One interesting alternative for this is the installation of a BESS. A properly connected BESS can help delay, reduce, or even avoid utility investments in distribution grids. Appropriate technology, sizing, and allocation within the distribution grid were identified as key factors for a viable operation [9, 33–35, 51, 87••, 88–90]. This is mainly achieved by smoothing the load (and/or RES production) curve by charging during non-peak demand hours and consequently discharging during peak hours.

S. B. Pienaar et al. [88] claim that BESS can optimally defer distribution upgrade when connected to the MV network. BESS is then placed on the congested side of the corresponding infrastructure (e.g., substation, overloaded transformer) and mostly placed downstream of the distribution feeder [9, 33, 89].

Usually, distribution upgrade deferral (D-GD) applications are of interest to DSO as well as C&I customers with increasing energy demand. Projects realized around the world support the above-mentioned claims.

In most D-GD applications, the battery's discharge time ranges between 1 and 4 h with a minimum of 500–1000 cycles/year [90]. For these specifications, lithium-ion is currently the most deployed battery technology for D-GD. According to US Department of Energy Global Energy Storage Database, 41 projects with D-GD as main or secondary application used Li-ion batteries with power capacities ranging from 30 kW up to 25 MW, the most out of electrochemical storage technologies [43, 91]. Other projects, specifically in USA and Italy, demonstrated the effectiveness of sodium sulfur (NaS) batteries in deferring distribution upgrades. NaS batteries are characterized with long-duration capabilities reaching up to 10 h [92].

To maximize the battery's economic potential, D-GD is also combined with revenue stacking. Literature shows the most common combination is with PS [33, 34, 43, 90]. This is due to congestion during specific hours. Moreover, depending on the battery type, capacity upgrade deferral can be combined with primary and secondary frequency reserves, voltage control, reactive power compensation, and RES curtailment minimization [22].

Using BESS for D-GD has not yet proven cost-beneficial for high demand growth, since this requires constant upgrading of the BESS itself. However, BESS works well in areas experiencing low to moderate demand growth [33, 35, 93]. It is of great importance to precisely forecast increases in demand, in order to correctly assign the BESS size and properly identify possible congestion areas within the distribution network [94]. Nonetheless, a traditional distribution system upgrade is still more cost-effective in areas experiencing high demand growth. Projects, such as Smarter Network System (UK), claim a payback period of 2.5 years over a 10-year economic lifespan for the BESS installed, where D. M. Greenwood et al. and P. Papadopoulos et al. [43, 95] discuss the techno-economic advantages of this project. The UK Western Power Distribution [96] also highlights the £1.2m net financial benefit of the WPD Falcon project in a 4-year trial, with this number reaching up to £660m over a 20-year lifespan.

Transmission Grid Upgrade Deferral

The reasons behind transmission grid upgrade deferral (T-GD) are similar to D-GD; the root cause of both is RES intermittency, increasing electrical demand, and low asset utilization that could make a well-placed BESS a preferred and cost-effective solution.

In addition, transmission lines face congestions due to increasing decoupling of electricity generation and consumption sites. Particularly, countries with widely diversified RE potential and/or little international HV grid interconnections carry for this reason high potential for such applications. In some cases, due to the topography of an area or areas facing public oppositions caused by new HV power lines in or through urban areas, BESS is considered a solution, regardless if it is a less financially favorable option [97].

Several publications [20, 98, 99] discuss the optimum placement of BESS within congested transmission networks. S. Wogrin and D. F. Gayme [98] analyze the siting of ESS based on the technology. The authors identify optimal allocation of energy-based storage technologies at the congested nodes within the transmission network. As for power-based storage technologies, co-location with RE production sites is ideal. Other papers challenge the effect of energy storage allocation within the transmission grid. L. Fiorini et al. [20] claim that in a renewable intensive grid, correct BESS sizing rather than allocation has a greater effect on optimizing the grid usage. Nonetheless, the installation of BESS in combination with high penetration of RES can decrease transmission line overloads by up to 80%. J. Salehi et al. [99] also mention the feasibility of combining RES such as wind energy along with a BESS to defer upgrade investment on a sub-transmission substation.

Lithium-ion batteries are the most common deployed technology in T-GD applications. This technology allows to stack revenues with high discharge and power applications together with T-GD [24•]. However, in the analysis of BESS in HV grids, R. Benato et al. [21] claim that there is also potential for energy intensive time windows (up to 8-h charge/discharge times), where NaS and sodium nickel chloride (zebra) technologies are supposed to be very suitable.

This is showcased in one of the most prominent projects in T-GD, the case of the Italian transmission operator TERNA. Here, excess wind energy in the south of Italy cannot be fully transported to the main consumption sites in the north due to limited transmission capacity, resulting in curtailing of wind energy. In 2015, they installed three NaS batteries at distinct substations, totaling 34.8 MW. All were part of the 150 kV HV network that aided in reducing congestions along the transmission lines [21, 94].

Obviously in T-GD, revenue stacking plays an important role in increasing economic BESS performance. The identified applications in revenue stacking are contingency grid support, reactive power compensation, and black start support [27].

Most of transmission and distribution grid upgrade deferral (T&D-GD) projects are currently being realized in North America and Europe. However, particularly countries with high financing cost and dynamic transmission grid development are projected to use BESS for T-GD especially in urban areas. A general rule on economic profitability linked to T&D-GD is still difficult. However, with battery prices declining and the benefit of revenue stacking, the use of T&D-GD will surely rise in the foreseeable future [24•, 25, 100].

Conclusions

The next step of a successful implementation of the energy transition relies strongly on the availability of flexibility options. In this context, BESS play a central role and are currently implemented on all levels of the power system in various countries. In this review paper, an overview on the currently most important applications of BESS is provided and summarized in a structured way in Table 1. The table shows which applications can be offered by which providers (and at which network level). Thus, the table helps in identifying the high potential applications as well as revenue stacking for each operator group.

Furthermore, the table contains an evaluation of the techno-economic potential and an overview of the most important identified scientific papers in view of the authors. In this way, a comprehensive overview of the various fields of applications has been created, from which the most interesting publications can immediately be extracted.

In addition, six of the most relevant applications were described in more detail. This selection is based on the authors' assessments, considering essential criteria such as general market potential, regulatory conditions for large deployment, and techno-economic suitability.

Beyond that, in the corresponding sections, the authors give a general introduction to the specific application and further describe who can provide the application to specific customers. All these sections include at least one example of a use-case where the application is highlighted in.

Abbreviations AS, Ancillary services; BESS, Battery energy storage systems; BTM, Behind-the-meter; C&I, Commercial and industrial; CAPEX, Capital expenditure; D-GD, Distribution grid upgrade deferral; DSO, Distribution system operators; ESS, Energy storage systems; FCR, Frequency containment reserve; FR, Frequency regulation; FTM, Front-of-the-meter; HV, High voltage; LV, Low voltage; MV, Medium voltage; NaS, Sodium sulfur; PS, Peak shaving; PV, Photovoltaics; RES, Renewable energy sources; SC, Self-consumption; SG, Synchronous generators; T&D-GD, Transmission and distribution grid upgrade deferral; T-GD, Transmission grid upgrade deferral; TSO, Transmission system operators

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Declarations

Conflict of Interest The authors declare no competing interests.

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Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

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