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Theme 1: Integrating New Flexibility Tools and Principles for Planning

Review of demand-side BESS management for participation in flexibility markets

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Pankaj O. Kela ✉, *Hannu Laaksonen, Ran Zheng, Chethan Parthasarthy*

Department of Electrical Engineering, University of Vaasa, Vaasa, Finland
✉ *E-mail: pankaj.kela@gmail.com*

Abstract: The dual-purpose use context of demand-side battery energy storage system (DS BESS) to meet customer objectives and provide grid services is considered. This study approaches towards evolving a cumulative view of DS BESS while highlighting distinct context of residential, community, commercial and electric vehicles (EVs). This work bridges the need for an aggregated view of DS BESS, that builds upon studies with a specific focus on EVs, residential BESS etc., while also infusing distinctive customer context and resulting practical constraints, into studies from the grid's perspective that delve into the multi-purpose role of BESS. This combination of the cumulative view of DS BESS along with distinctive customer context is important for much needed regulatory developments as also network reinforcement decisions.

1 Introduction

Active (*P*) and reactive power (*Q*) control potential of the distribution network (medium voltage [MV] and low voltage [LV]) connected distributed energy resources (DERs) must be utilised increasingly in the future power systems to manage different variabilities related challenges. DERs can consist of distributed generation (DG), battery energy storage systems (BESSs), demand response or electric vehicles (EVs). These DERs can provide flexibility and resiliency for local (distribution system operator, DSO) and system-wide (transmission system operator, TSO) needs, enable large-scale integration of renewable energy resources (RESs) and EVs as well as minimise the whole system and society costs in order to maintain customer electricity prices at a feasible level. However, this requires the combination and coordination of different types and sizes of flexibilities from all voltage levels (LV, MV and high voltage [HV]) [1]. The fast and controllable dynamics of BESSs have the potential to provide multiple different grid services. In many cases use of BESS only for one purpose, for example, improving electricity supply reliability (intended islanded or microgrid operation) or increasing distribution network/photovoltaic (PV) hosting capacity [2, 3] may not be an economically viable solution. Therefore, also other use cases are needed for distribution network-connected BESSs. However, then potential conflicts between different control functions and their settings need to be carefully considered.

In general, the BESS control and management schemes can be roughly divided into local, distributed and centralised methods [4, 5]. The management scheme can be also hybrid, i.e. combination of centralised and distributed control features. In addition, different control methods have been also proposed from the BESS dynamic response point of view, like for example in [6] to improve the inertial response of the BESS.

2 Potential of demand-side BESS (DS BESS)

The superior potential of behind-the-meter battery energy storage systems (BtM BESS), when compared to a connection at other electricity network levels, to provide different grid services and enhance network performance is highlighted in [7]. Simulation results in [8] show that grid challenges, addressed by BESS in LV grids, have positive multiplicative impacts on upper grid levels. Thus, it is exceedingly desired for BtM BESS to provide grid services and improve the flexibility of operations. This brings to focus investments in BESS by retail electricity customers, referred to as demand-side BESS (DS BESS).

Systems thinking-driven study of residential solar and BESS adoption in Australia highlights decisions in an early phase of DS BESS uptake could have lasting effects on how it is deployed and used in future [9]. Studies from Australia and Germany underscore the residential customer's preference for a high level of self-sufficiency and grid-independence [10, 11]. This is a significant non-financial factor that would inform customer choice for ownership and control of BESS. Thus, quoting from [9], 'responsible stewardship will require a clear articulation of policy intent, supportive regulatory environment and a forward plan so that the market can develop and respond to regulatory signals'.

This paper approaches towards evolving a cumulative view of DS BESS while highlighting the use context of residential, community, commercial and EVs. Further, a viable path towards an increasing level of grid-integration of DS BESS is suggested, while identifying challenges in attending to these. This work bridges the need for an aggregated view of DS BESS, that builds upon studies with a specific focus on EVs, residential BESS (R-BESS) etc. while also infusing distinctive customer/user context and resulting practical constraints, into studies from the grid's perspective that delve into the multi-purpose role of BtM BESS. This combination of the cumulative view of DS BESS along with distinctive customer context is important for much-needed policy and regulatory development as also network reinforcement decisions. Also, optimisation of BESS multi-use in different cases and markets [12] for local (DSO) and system-level (TSO) purposes will be important from the BESS owner's point of view.

3 DS BESS adoption and applications

Increasing self-sufficiency is the primary motivating factor in R-BESS adoption. A study of 369 residential customers in the USA [13], finds that 'majority of customers can exceed 70% self-sufficiency with a 20 kWh battery and a PV system that

Table 1 Customer types and their prominent BESS applications, ownership modes, default BESS operating mode and tools/mechanisms to enable grid-supporting operation

Customer type	Prominent DS BESS application	Ownership modes	Default BESS operating mode	Tools/mechanisms to enable grid-supporting operation
residential	increased PV self-consumption	own	grid independent	• Smart meter [19]
community	increased consumption from local sources; microgrid	right of use, subscription model	grid independent/grid supporting	• Local controllers • Home energy management • Net metering; FiT
commercial	demand charge reduction; backup power	own, right of use	grid supporting	• Third-party BESS operators
EV	transport	own, rent	grid independent	• TimeOfUse tariff, dynamic pricing • Smart charging stations

produces the equivalent of their consumption' compared to average 35% self-sufficiency with PV only system. Further, retail electricity prices above \$0.40/kWh and feed-in-tariff (FiT) below \$0.05/kWh are likely requirements for PV-battery systems to be more profitable than PV only systems. A study of 261 households in Australia simulates PV and battery investment decisions for alternative FiTs over 20 years [14]. For FiT rates below 50% of volumetric usage charge, PV and battery installations are sufficiently cost-effective to reduce grid imports by over 92% at the end of 20 years. On the other hand, electricity retailers incur significantly reduced revenue for FiT's above 75% of volumetric usage charge. Thus, it is economically challenging to restrain customer PV-battery adoption and 'evolutionary market pressures will require the energy market to integrate a growing quantity of distributed energy resources'.

In [15], a novel methodology is designed to identify optimal community BESS (C-BESS) for increased PV self-consumption. Simulations plot the optimal C-BESS capacity for different community sizes (number of homes from 1 to 100). For two different BESS technologies (PbA, Li-ion) and under different community PV percentages (proportion of homes in a community with a PV array), a single R-BESS is never the optimum case and always results in a higher levelised cost of energy storage (LCOES) and lower internal rate of return. For example, a 20-home C-BESS with a low community PV percentage of 37%, still had lower LCOES compared to R-BESS. Additionally, 'more uncorrelated the demand among different homes, more benefits are introduced by the community approach'.

Load peaks of commercial buildings typically have high temporal coincidence with solar energy production. Thus, while investment in PV systems seems attractive, adding BESS minimally affects PV self-consumption [16]. However, irrespective of PV installation, BESS can profitably support particular commercial and industrial customers when the storage strategy is optimised considering two aspects: to decrease the power draw from the grid during peak hours and to reduce the energy consumption of peak hours by shifting the needs to off-peak periods [17].

2015 survey [18] of a database of stationary battery projects across the world, the largest share of projects (36%) were dedicated to arbitrage applications, the majority of which were electric bill management at the consumer level (23%). 69% of these projects had explicitly mentioned secondary BESS applications – a common combination being consumer power reliability with increased utilisation of residential solar PV. Table 1 maps the different DS BESS applications to corresponding customer types, ownership modes and default BESS operating modes.

4 Grid support and flexibility market participation

Flexibility can be characterised along three dimensions: absolute power output capacity range (MW), speed of power output change or ramp rate (MW/min) and duration of energy levels (MWh). The concept of 'flexibility market' responds to the emergent need for a transparent market value of flexibility. For example, markets can provide market and financial structures that pay (or pay more for) desired flexibility attributes [20]. Alternative flexibility market models are under development with, among other things, particular discussion considering the role of DSO. The DSO-coordinated project InterFlex, reports two approaches, an integrated approach where the DSO is the flexibility operator/aggregator and a market approach where the DSO procures flexibility from market stakeholders (aggregators, consumers, generators) [21]. A more general discussion of the properties of flexibility models is shared in [22], which then compares based on these properties two models – a fully market-driven model (open market model) and a more grid-centred model (secondary market quota model). The former is more suitable for achieving an efficient price level for users whereas the latter is more in line with the needs of the DSO. It is suggested to combine the advantages of both these models in order to satisfy both sides equally. Both these models depend on the accuracy of grid state forecasting. Thus, until a final model has been identified, it is recommended to develop network management processes and systems to optimise network forecasting and precisely identify the need for flexibility.

Recognising the extended setup phase of mature flexibility markets and the simultaneous need to stimulate such a market with actual customers and technical and commercial aggregators, Fig. 1 shows the viable evolution phases in the level of grid integration of DS BESS as the DS BESS capacity increases. In the first phase with very low installed capacity, the DS BESS operates independently of the grid state. In the next, 'Grid Supporting' phase, DS BESS operations and control increasingly take into account the grid state. Table 1 lists the tools/mechanism to enable increasing grid supporting operation of DS BESS. These concepts either improve or incorporate the improved grid state-forecasting measures. Finally, with the maturity of flexibility market models and the increasing volume of DS BESS installations, flexibility market participation could be the feasible economic and technical choice for DS BESS operation and control. The right axis prompts the hierarchy of actions to give a suitable nudge to the stakeholders: the regulatory framework sets the stage for tariff regime, which enables and helps unlock the market value of flexibility.

4.1 DS BESS aggregation

The multiple roles of DS BESS in providing grid services are shared in [7] including whether an aggregator is needed for the provision of

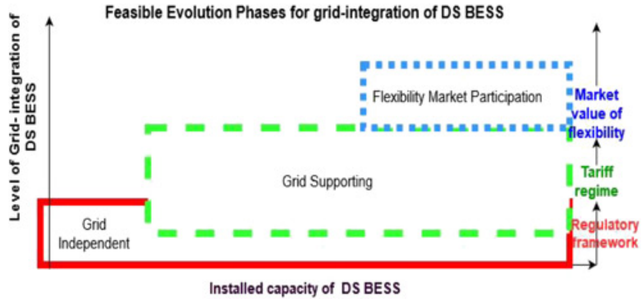

Fig. 1 *Evolution phases for grid integration of DS BESS*

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the particular grid service. For example, the aggregator is not necessary for the provision of frequency regulation but the aggregator is 'helpful to make sure this service and others do not interfere with each other'. Thus, the exploitation of DS BESS to provide load frequency control, both as 'Coordinated Aggregate Systems' as well as 'Non-Coordinated Individual Systems' is surveyed in [23], sharing also the challenges of each of these methods.

Commercial BtM BESS used for demand charge management usually have considerable idle periods [24]. Thus, aggregation of these BtM BESS allows them to participate in multiple wholesale markets and provide ancillary services, maximising owner's payoff.

4.2 Flexibility from EVs

EVs, in addition to the flexibility in battery utilisation, have the possibility to offer flexibility from charging schedule, the amount of charged energy, charging duration and charging location. Smart Charging and Dynamic Pricing are two possible approaches to address challenges from the increasing penetration of EVs. Dynamic pricing, in which DSOs or an operator/aggregator charging stations dynamically adapt prices is exhaustively reviewed in [25]. The author opines limitations of these studies are that most assume perfect knowledge of charging demands (rather than a forecasting model) and further several approaches also assume knowledge of user preferences.

4.3 Customer engagement initiatives

A showcase of BtM BESS applications and projects is shared in [26]. Among these projects, the potential of residential PV and BESS applications is tapped into directly by few DSOs (Green Mountain Power – Vermont USA; Eneco's CrowdNett – Netherlands) through novel schemes that sharply discount upfront BESS costs in return for access to some of the BESS capacity to support grids. On the other hand, the deployment of commercial BESS is supported by dedicated energy service providers with expertise in data analytics for real-time optimisation of BESS operation to reduce costs at the level of a building or a fleet of energy storages.

A novel example is of the manufacturer of solar home batteries in Germany, sonnenBatterie which has evolved towards sonnenCommunity, a virtual energy pool shared among members and providing grid services to the public power grid.

5 Conclusion

Different customer types have distinct DS BESS adoption and application context. The integration of these DS BESS in the grid to provide grid services can be pursued in different phases. C-BESS projects and associated business models merit increased proactive exploration.

To purposefully guide future research, it is worth considering the definitive conclusions and contextual constraints learned from the many project and simulation studies. For example, residential BESS installations could either be considered as a sub-system in-home energy management system that participates in demand response or directly is engaged in grid services. Another research direction is the criteria for developing independent response versus aggregated response to grid service requests. Finally, grid-supporting mechanisms and flexibility market developments need to keep pace with DS BESSs adoption rates. Thus, early engagement among all stakeholders is important to guide the DS BESS grid-integration pathway.

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