# INTEGRATION OF DISTRIBUTED ENERGY STORAGE SYSTEMS AS A SHARED RESOURCE IN DISTRIBUTION NETWORKS

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## ABSTRACT

*Distributed Energy Storage Systems (DESS) can provide multiple services ensuring benefits to several actors of the electric sector, particularly in the presence of high shares of renewable energy sources (RES). However, their integration in distribution networks still presents multiple inherent technological, regulatory and economic barriers. The lack of a specific regulatory framework that allows an adequate quantification of DESS technical and economic benefits along with their high deployment costs hurdle a comprehensive approach to the DESS' integration problem in distribution networks.*

*This study proposes a novel business framework for DESS, introducing these new technologies as shared resources in distribution networks. This means that a DESS owner may share its energy and power capacity in order to maximize its value and, therefore, increase the potential of storage systems in distribution networks.*

## INTRODUCTION

Distributed Energy Storage Systems have been gaining attention from different stakeholders across the electric sector value chain. Their capability of charging, discharging and accumulating energy influence both the supply and demand side, allowing the provision of a wide range of services to different stakeholders of power systems [1]. Therefore, DESS is expected to play a crucial role in moving towards smart grids and a more decentralized planning and operation of electrical systems [2]. The ever growing levels of RES, the increasing peak demand in many parts of the world and the deregulation of the electric sector may trigger the proliferation of such technologies if they present themselves as technically and cost effective when compared to alternative solutions.

DESS may provide services such as capacity support and voltage regulation to the distribution system operator (DSO), ancillary support and curtailment minimization to RES promoters/operators and peak shaving and minimization of electricity costs for customers. Although connected to distribution networks, DESS may even provide services to transmission system operators (TSO) such as frequency control and congestion relief [3]. Moreover, performing a single service is often recognized as insufficient for DESS to generate revenues that surpass its costs (investment, operation and maintenance) [3, 4]. This shows the importance of maximizing revenues from different services provided to different stakeholders.

This work proposes a novel business model for DESS presenting these new assets as shared resources in distribution networks. The proposed business model consists on a framework for aggregating values of DESS where power and energy capacity of DESS are used by different distribution network stakeholders. The value streams of DESS may derive from both regulated activities such as voltage regulation and reactive compensation, and market-driven activities such as regulation market participation and arbitrage.

## ENERGY STORAGE SYSTEMS IN DITRIBUTION NETWORKS

Distribution networks present several opportunities for the integration of DESS. These are related with a deregulated electric sector that allows the participation of a multitude of stakeholders, an ageing distribution infrastructure that must cope with electricity demand growth and the increased presence of RES that, despite its inherent benefits, further stress distribution networks operation [1]. Indeed, the continuous integration of variable RES is one of the main drivers for the adoption of DESS. Renewables present technical and economic challenges that need to be addressed in order to potentiate the penetration level of these sources while keeping high energy quality supplied to costumers [5]. DESS may cope with the increasing needs for higher flexibility, reliability and power quality while enhancing the technical and economic value of RES.

Nonetheless, there are still important barriers to an adequate integration of DESS in distribution networks. The lack of a specific regulatory framework hurdles the creation of an integral business model for DESS that is capable of accurately quantifying its benefits and costs. Moreover, DESS technologies, particularly battery based storage systems, often present reduced useful lifetime when compared with conventional distribution assets such as tap-change transformers or capacitor banks. Along with the currently high investment costs of DESS, the aforementioned challenges difficult a fair and non-discriminatory comparison with alternative solutions such as demand response or the traditional distribution network upgrades such as lines and transformers.

### Technologies: from characterisation to impact

Grasping DESS technologies is fundamental to properly accommodate and utilize them in power systems, particularly in distribution networks. Their main characteristics such as energy and power capability, response time, cycle life and investment costs reveal their expected performance. Moreover, as the storage device is usually connected to the distribution network through power electronic systems, DESS can also inject reactive power. These characteristics allow the selection of the most suitable technology for a given application when planning the integration of DESS in distribution networks.

The main DESS technologies currently commercially available are flywheel, ultracapacitor and battery based systems [6, 7]. Although both flywheel and ultracapacitor systems tend to have high power capability, their low energy density and reduced discharge durations make them suitable mainly for power applications. Instead, battery based systems (e.g. Lead-acid, Li-ion, Nickel, Sodium-sulphur) rely on chemical manipulation processes that may confer, depending on the chemical material, a capability of managing applications that demand both power and energy availability [8]. Therefore, when several different services are procured, battery systems stand out as the most adequate technological solution. Nevertheless, the developed work is technology agnostic i.e. does not intend to favour the acceptance of any particular technology but rather enable it to understand and accommodate other systems with similar characteristics.

## Applications and Business Models

Energy storage may provide benefits to several stakeholders involved in the electric industry. Although this feature has been a driver to the integration of storage systems in power systems [1], it has also presented challenges as it is difficult to establish a business model due to the existence of multiple beneficiaries and an unclear quantification of the benefits and costs.

Moreover, some of the benefits that may be provided are externalities i.e. "split benefits", meaning that some stakeholders may benefit from it despite not contributing to its implementation nor request DESS action. For example, a DESS performing voltage regulation to the distribution system operator may avoid RES curtailment increasing the profits of the RES owner. The way benefits and costs may be shared among different stakeholders pose challenges to the adoption of energy storage and raise a regulatory framework concern. Also, in several European countries, DSO's are usually constrained to pursuing intrinsic services, due to their regulated activities focus, rather than market-driven activities [1]. Therefore, the regulatory uncertainty may reduce the potential impact of DESS deployment.

### Stakeholders' perspectives on DESS services

In distribution networks, DESS can be regarded according to the perspective of different stakeholders: the Distribution System Operator (DSO), Independent Storage Systems Operator (ISSO), RES promoters and customers. The ISSO's concept may represent different stakeholders such as energy traders, retailers or aggregators. Customers may refer to a large industrial consumer or a "*prosumer*" i.e. a customer that focuses on both consumption and production.

Table I presents the panoply of services that DESS may provide according to the stakeholder perspective. The enumeration of DESS services is mainly focused on the most valuable services already recognized on previous studies [3, 9].

Furthermore, Table I indicates the services that may be procured according to the intrinsic activity of each stakeholder in distribution networks. This means that, on one hand, a combination of services may be procured regarding the stakeholder' needs and, on the other hand, services to meet other stakeholders' needs may also be provided to increase the value of DESS.

Table I – DESS services according to the stakeholder perspective

| *Perspectives \Services* | *DSO* | *ISSO* | RES promoter | Customer |
|---|---|---|---|---|
| Capacity support | ✓ | | | |
| Arbitrage | | ✓ | | |
| Regulation Markets | | ✓ | | |
| Voltage Control | ✓ | | ✓ | ✓ |
| Contingency support | ✓ | | | ✓ |
| Reactive compensation | ✓ | | | ✓ |
| RES Curtailment minimization | | | ✓ | |
| Ancillary Services | ✓ | | ✓ | |
| Peak Shaving | ✓ | | | ✓ |

One relevant question about energy storage and particularly DESS is its ownership and controls responsibility. While for some of the services referred in Table I this question has a straightforward answer, in others, especially if a combination of DESS services is to be considered, the question is rather pertinent. For instance, if a storage device is deployed by an industrial customer to perform peak shaving, it is clear that the storage may be owned and operated by that industrial customer. However, if the DESS is to perform different services to different stakeholders, DESS owner may be any distribution network stakeholder.

DESS planning should, therefore, aim at the combination of the most valuable services which may result in having revenue streams from competitive activities on one hand and from the provision of regulated services on the other. Moreover, the combination of services should be compatible and feasible within the same technology.

## DISTRIBUTED ENERGY STORAGE SYSTEMS AS SHARED RESOURCES

A novel business model for the integration of DESS is proposed, where these assets are presented as shared resources in distribution networks. The concept encompasses a framework for aggregating values of DESS by optimally allocating storage capacity to perform multiple distribution network services to several players. The business model consists on a single stakeholder owning and operating one or multiple DESS. The owner uses DESS to perform services related with its intrinsic activity. The remaining storage resource is then shared for other service provision with any interested stakeholder within the distribution network. The DESS owner establishes its operating strategy by properly aggregating the different services and optimally allocating storage capacity (Figure 1).
Sharing the storage resource allows additional revenue streams that may result from contracted services and/or storage market. The first value stream relies on services where the DESS owner(s) contractually guarantee the commercial control to a third party i.e. assure the availability of a certain DESS power and energy capacity in certain periods. For example, an ISSO may offer peak shaving and voltage regulation to the DSO during specific periods of the day. The second value stream consists in organizing a series of auctions for the use of the remaining storage capacity in which other stakeholders may participate. Furthermore, the proposed storage market may encompass different time horizons (e.g. day-ahead to hour-ahead auctions) as different services may require different time-scales. Nonetheless, the resulting storage schedule must not put at risk the realization of other more valuable or contracted services as the goal is the maximization of the income streams.
The existence of remaining storage capacity depends on the value of the services provided and the DESS sizing. Often the minimum size to perform a combination of services is the economic optimal size of DESS [7]. This means that the value provided by extra capacity needs to surpass its associated deployment costs.

### Aggregation of DESS values

The concept of DESS as a shared resource is the core characteristic of the proposed business model.
DESS owner can grant the availability of power and energy for different distribution network actors. Therefore, revenues are increased which improves the cost effectiveness of DESS. Moreover, benefits are shared and extended to other stakeholders contributing to enhancing the overall value of DESS.
Nonetheless, in order to achieve the potential welfare of sharing the storage resource, an adequate aggregation of DESS values and an optimal allocation of power and energy capacities through time must be performed.
The state of charge (SoC) management is an essential point for an accurate aggregation of DESS values. The estimated SoC must be managed properly as it may otherwise limit the provision of different services and reduce the value of DESS. When allocating DESS capacity, key DESS characteristics must be taken into account, some of which inherent to the DESS technology. Not only the power range and energy capacity must be considered, but also charging and discharging efficiencies as well as the maximum depth of discharge (DoD) of the system [10]. The maximum DoD is limited in some technologies such as lead-acid batteries in order to extend their useful lifetime [6].

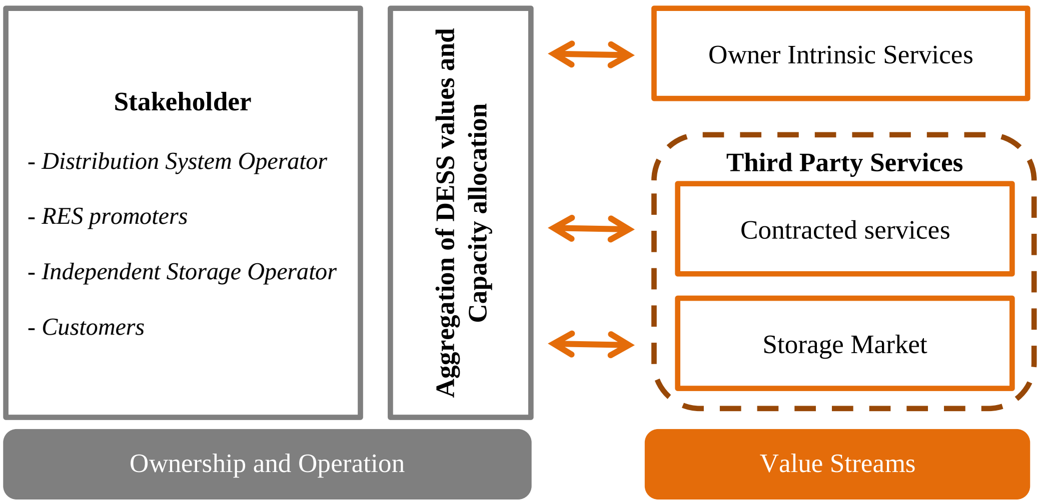

Figure 1 - Proposed business model for maximization of DESS value

DESS capacity allocation needs to cope with its ability to inject active and reactive power in the distribution network as both are required to perform several services. Reactive power, despite its limited impact on DESS' SoC, is constrained, along with active power, by the apparent power of the power conversion system that connects DESS to the distribution network

**Owner intrinsic services and Contracted services**

The power and energy requirements for DESS to perform its owner intrinsic services need to be calculated. This is crucial to properly allocate storage capacity and potentiate the aggregation of other DESS values. Depending on the nature of the intrinsic services to be provided, different techniques may be applied to anticipate the power and energy requirements. Techniques based on historical data time-series as well as forecasting techniques may be applied to define the charging and discharging schedule of DESS. For example, an industrial costumer aiming at utilising DESS to perform backup reserve may allocate storage capacity according to its average electricity demand profile. In the case of a RES promoter aiming at firming its renewable output, advanced forecasting techniques may reduce the DESS' energy requirements [2].

The power and energy requirements for contracted services are established by the respective stakeholder that communicates its needs to the DESS operator. The aggregation of DESS values depend on the type of contracts established as well the kind of services involved. Different third-party contracts may be established and the DESS operator must cope with them in order to fulfil their objectives. For example, contracted services may be remunerated according to power or energy delivered or simply by capacity availability.

## Energy Storage Capacity Allocation

The allocation of DESS capacity is performed in different time horizons, from week-ahead scheduling to day-ahead scheduling. This approach is justified by the different combinations of services that can be involved and that require different time frames. For instance, due to the more predictable behaviour of load, power and energy capacity allocation for peak shaving may be achieved for a wider time frame. However, sharing capacities for electricity markets participation is constrained by the specific auctions time frames (e.g. day-ahead or intra-day auctions). Moreover, anticipating the capacities to allocate contribute for a better management of the SoC of DESS as it may be smoothly adjusted to cope with future capacity needs.

Scheduling DESS consecutively closer to the moment of power delivery contribute to the optimization of its capacities. It allows power and energy previously allocated to owner intrinsic services and/or third party contracted services to be adjusted and thus a more accurately DESS schedule may be defined. In fact, the closer to the event the capacity allocation is performed, the more detailed information or more accurate forecast about distribution network conditions are available for the involved stakeholders. Therefore, a more efficient DESS scheduling strategy is achieved.

In electricity markets, stakeholders may be remunerated for their availability of power whether it is used or not. For example, in regulation markets such as secondary or tertiary reserve markets, participants are paid according to their available power (and energy) for upward and downward adjustments which may be used, or not, depending on the behaviour of the power system. DESS capacities allocated for this kind of services may not be used, making them available for later periods. Therefore, allocating DESS capacities in closer to power delivery time frames allows the maximization of the effective utilization of energy storage.

**Storage Market**

In the electric sector, the closer to real time power is available to be supplied, the more valuable it stands. For example, regulation market prices often present higher prices than spot electricity markets [10]. In the presence of high shares of variable and limited-predictable RES, power availability to compensate the upward and downward variations of renewable power is precious. The proposed concept of storage market aims at exploring DESS remaining capacities closer to time of power delivery in order to enhance storage value in distributions networks. Consequently, allowing power adjustments closer to events make DESS available for providing services of higher value. The storage market takes place in intra-day auctions, from day-ahead to hour-ahead auctions. Therefore, this feature of the proposed business model is complementary of the capacity allocation to perform contracted services and owner intrinsic services.

Additionally, the storage market constitutes the place where DESS owner may share its storage resource with a wider range of distribution network participants. Stakeholders without contracted services may utilize the shared resource sporadically when DESS may increase the value of their own activities. RES promoters which develop activities with inherent uncertainty due to the variable and limited-predictability character of RES may take advantage of the existence of a storage market. Nonetheless, only the most valuable services of DESS are accepted in storage market auctions. Likewise traditional electricity spot markets, the proposed storage market may also present offer (DESS operator) and demand (other stakeholders) curves where a pay as bid approach for all participants is proposed. Each request in the storage market represents also a cost to the DESS owner. Consequently, only bids above the marginal cost associate with the required capacity may be fulfilled. The marginal cost of performing a certain service is dictated by the DESS' technology and underlying characteristics of cycle life and investment cost. For example, a lead-acid battery may perform about 1000 cycles at 80% of DoD but may perform 100 000 at 10% [6]. Therefore, the allocation of capacities in the storage market must consider not only the current cycle but also the previous ones to measure the correspondent marginal cost. Moreover, the resulting schedule from the storage market shall not hamper the provision of owner intrinsic services and contracted services.

## Multiple distributed energy storage systems

A distribution network stakeholder may be the owner and operator of more than one storage system. For example, the DSO may deploy several DESS at different locations not only to improve the efficiency and flexibility of the distribution network but also to provide services to other stakeholders. Also, a RES promoter owning more than one wind park may introduce storage systems at each of those locations.

The presence of multiple DESS that are owned and operated by the same stakeholder influence the process of aggregating DESS values and the allocation of capacity as it may regard the location of the storage systems. For instance, services such as voltage regulation require considering the location of DESS due to the voltage' different sensibilities to the injection of active and/or reactive power along the distribution network. Moreover, the proposed business model is capable of handling multiple DESS as the allocation of capacities are performed in different time horizons which allow transferring the allocated capacities between the available storage systems.

## FINAL REMARKS

Distributed energy storage systems are fundamental to tackle the challenges of present and future distribution networks as they can fulfil a variety of functionalities and provide benefits to various stakeholders. The main challenge posed to DESS is how to aggregate multiple services and to maximize several value streams as focusing in one specific application is often not cost-effective.

This work proposes DESS as shared resources in distribution networks, framing these new assets within a viable business model. The approach consists on aggregating DESS values by sharing their capacity not only to perform owner intrinsic services, but also to perform contracted services and make available storage capacity through a storage market. The proposed business model contributes to the enhancement of the storage value in distribution networks as it allows the procurement of several high valuable services.

The adoption of this business model may facilitate the deployment of DESS as it increases the profitability of these assets which is essential to surpass their usually high investment costs. Nonetheless, the establishment of a storage market depends on the DESS sizing as services to other stakeholders need to economically justify the additional storage capacity required. Furthermore, the framework may represent a foundation for an adequate assessment of the technical and economic impacts of DESS in distribution networks. The regulatory scope changes needed by the developed business model may already be reduced in North American and European regulatory environments.

The framework, however, requires an advanced information and communications technology infrastructure and an adequate interaction between different distribution network stakeholders. These challenges represent additional complexity in the operation of distributed storage systems and the supporting distribution network.

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