Business Case for Distributed Energy Storage

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ABSTRACT

This paper present the analysis carried out to quantify the value that distributed energy storage (ES) installation may deliver to its owner by simultaneously providing multiple services to a number of entities in the electricity sector. In this analysis a full spectrum of services that ES may deliver are considered: energy arbitrage, balancing services, supporting low-carbon generation, network support, frequency regulation services and capacity market. The results demonstrate that the net revenues from any single service would be difficult to justify the relatively high investment cost. Optimized provision of multiple services is therefore the key route for ES to make a profitable business case in the market. The potential synergies and conflicts between TSO and DNO services supplied by ES are also analysed.

INTRODUCTION

As an emerging technology to support the integration of renewable energy resources (RES), energy storage (ES) attracts extensive attentions in recent years. The main profit stream for ES is temporal arbitrage opportunity created by price volatility in either or both energy market and real-time market. The capability of ES to perform energy arbitrage has been studied in [1] [2] [3], while providing ancillary services has been shown to increase the value of ES [4] [5]. These studies are all based on the prices in the present market environment, but the integration of RES and other low carbon generation technologies may potentially increase the volatility for system prices [6]. Furthermore, some updated market arrangement (e.g. real-time procurement of ancillary service) and new markets (e.g. capacity market) have been recently discussed or even implemented to tackle the challenges imposed by the integration of RES, the impact of which on the value of ES is yet to be determined. Finally, as demonstrated in [7], ES is capable to bring multiple saving across different sectors, including generation, transmission and distribution. The synergies and conflicts between TSO and DNO services supplied by ES need to be analyzed when allocating ES resource to different markets and services. In this context, this paper develops an assessment framework based on the GB market structure to analyse the profit of distributed ES when simultaneously providing multiple services.

IDENTIFICATION OF SERVICES THAT ES COULD PROVIDE

This section provides an overview of services that ES could potentially provide to a variety of entities in the power sector, ranging from transmission and distribution network operators to market participants and consumers. The list of services is non-exhaustive – there could be other services where ES could contribute, however those considered here are deemed to represent the most promising commercial opportunities for utilising ES.

It has to be noted that some of the services discussed here have already been procured by various actors today. Nevertheless, we also take a more forward-looking view by analysing the opportunities for using ES to also provide services that are not commoditised in today's system, but will be highly compatible with the policy objective to decarbonise electricity supply. The following list describes the key services where ES may be an important contributor:

- *Energy arbitrage*: participation of ES in day-ahead energy market. It involves using ES to take advantage of electricity price differentials by discharging during high-price periods and charging during lower-price periods.
- *Balancing services*: participation in real-time balancing market by providing short-term operating reserve to TSO.
- *Frequency regulation services*: providing primary, secondary and tertiary frequency regulation services to TSO. These services require rapid response and would be particularly suited for ES.
- *Capacity market*: contribution to firm supply capacity during high demand period. Participation of ES in this market may reduce the need to keep low-utilisation peaking plants in the system.
- *Supporting low-carbon generation*: flexibility provided by ES can support meeting the carbon targets at lower cost, due to lower need to invest in capital-intensive low-carbon generation capacity.
- *Network support*: placing ES at strategic locations in the distribution grid may provide support to DNO to reduce the need to reinforce the network to cope with peak loading conditions.

There may be conflicts between services that the optimisation of ES revenues needs to take into account.

On the other hand, there may also be synergies, where the provision of certain services makes it easier, or coincides in terms of energy delivery, to provide others.

For instance, when looking at energy arbitrage and DNO network support services, if the periods of high system demand and high market prices coincide with the periods of high demand at the distribution network level, it is clear that both services will drive ES to discharge during the same time period, presenting clear synergy between the two services. However, if peak demand conditions in the local distribution grid do not coincide with high system demand, these two services would be conflicting, i.e. it would not be possible to provide one of them without a negative impact on revenues from another.

Other types of conflicting service combinations could be identified, such as: a) balancing services reducing opportunities for energy arbitrage due to the need to maintain sufficient headroom and energy in ES to provide balancing when called upon; or b) frequency regulation services, when required to be provided throughout a month or a season, may limit the opportunities from energy arbitrage or network management as a part of storage capacity would be continuously allocated to frequency regulation. For an adequate assessment of revenue opportunities for ES from multiple services, the assessment framework needs to consider all of these conflicts.

METHODOLOGY AND ASSUMPTIONS

Assumptions on the market arrangements

Quantitative studies presented in this section assume an advance contracting market structure, where there is a short-term power exchange (STPX) with hourly energy prices available on a rolling basis. At the time of delivery, however, some participants may be unable to provide the contracted energy due to plant outages or fluctuations in available generation (e.g. wind or PV) or changes in demand. Therefore, TSO re-dispatches the system in real time to manage system imbalance. In particular, flexible resources would bid into the balancing market to balance the supply and demand.

Any real-time generation imbalances are cleared through the balancing mechanism. Any shortage or excess in the physically delivered energy with respect to the contracted position is charged by system imbalance price. To avoid the risk of high imbalance charges, a market participant could buy a balancing contract with another party so that if one party were short on its contractual position, the second party would increase output to keep the group in balance and hence avoid being exposed to imbalance charges. This may be particularly relevant for PV/wind farms due to the difficulty associated with accurate forecast. In such situation, the combined operation of ES and PV/wind farm may become attractive.

Quantifying revenues from ES operation

The annual value of ES from commercial operation is calculated by dividing its annual gross revenues with its capacity. The studies are carried out in two stages:

- The first stage is to derive energy prices, imbalance prices and frequency response prices on a rolling basis by using the advanced stochastic system scheduling model [8].
- In the second stage, with the assumption that the capacity of ES under investigation is sufficiently small to be considered as price taker, the stochastic ES scheduling model determines the operation of ES to maximize its expected revenues, based on the price information passed by the system scheduling model and a scenario tree that describes the possible realizations of available PV generation.

PV farm is assumed to submit the persistently forecasted output as the final position at the close of STPX. ES could therefore support the PV farm by reducing the penalty charge on the mismatch between contracted and realised PV output, while still participating in other markets to maximize its overall profit.

ES could also provide *frequency response* (FR) service to TSO by quickly adjusting its charging/discharging power. To provide FR in certain hour, ES is required to have sufficient headroom to increase its supply of active power as well as enough stored energy to sustain the increased power supply for 30 minutes. These constraints are included in the ES revenue maximisation model.

Under the present GB electricity market arrangements, the required volume of FR is contracted for the duration of a month or a week, at least a week ahead of real-time operation. The FR service is required to be available across the day or during chosen hours for the whole contracted period. However, our analysis has clearly demonstrated that the value of FR provision varies significantly over time depending on the level of net demand. We carried out simulation by using advanced stochastic system scheduling model [8], which also captures the impact of reduced system inertia on the FR requirements. The marginal cost of FR provision during each time interval is used as the FR price. This is calculated by comparing system operation cost with and without 100MW freely available FR. The marginal cost in 2030 may vary from almost zero in high net demand condition to more than £200/MW/h in low net demand condition.

Furthermore, as the penetration of intermittent RES increases, it will become increasingly difficult to accurately estimate the net demand level with long lead time. These developments raise questions over the efficiency of present FR market arrangements. New market arrangement for FR is required in the future low inertia electricity system. ERCOT has considered to introduce hourly ancillary service market in day-ahead market clearing with both FR and fast FR included. We therefore also consider a more flexible market arrangement, which allows the provision of FR to be determined at the close of STPX. Under this market arrangement, ES could optimise the provision of FR based on the FR prices and the prices of other services.

Finally, *capacity market* has recently been implemented in UK and US to ensure capacity adequacy. In order to be eligible to participate in the capacity market and obtain the associated payment, participants need to commit to provide a certain amount of energy production or demand reduction during peak hours determined by TSO for the year ahead. In this paper, participants are assumed to be available to deliver electricity for 4 hours during peak conditions over 10 days with the highest peak demand in a given year. ES could participate in the capacity market by holding power headroom and stored energy available for these pre-determined hours. These constraints are incorporated into the ES revenue maximisation model if ES participates in the capacity market.

CASE STUDIES

A set of case studies are carried out to investigate the application of distributed ES for the provision of multiple commercial services under the 2030 UK Gone Green system scenario. The storage installation under investigation is assumed to be equipped with 4-hour energy capacity and 75% round-trip efficiency. As shown in Table 1, the value of ES is quantified and compared under different operation strategies. There are six services considered in the study, and the cases are constructed by gradually stacking these services. The benefits of layering additional services are illustrated step by step.

Table 1. Service provision by ES across case studies

	Case	*Case*	*Case*	*Case*	*Case*	*Case*
Energy	✓	✓	✓	✓	✓	✓
Balancing		✓	✓	✓	✓	✓
PV			✓	✓	✓	✓
Network				✓	✓	✓
PFR					✓	✓
Capacity						✓

Energy arbitrage and balancing service from ES

Figure 1 presents annual revenues of ES by participating in energy and balancing markets. The value of ES is about £42/kW/year when ES only performs energy arbitrage. In this case, the revenues would hardly justify the investment of ES. However, the value of ES increases to £180/kW/year when it provides both energy arbitrage and balancing service. This is due to the increased balancing challenges in the future UK system driven by high penetration of RES. In particular, frequent calls upon standing plants with high marginal cost to manage sudden RES drops are likely to lead to very high imbalance prices. Participating in balancing market enables the ES to benefit from these high prices and thus enhance its commercial value.

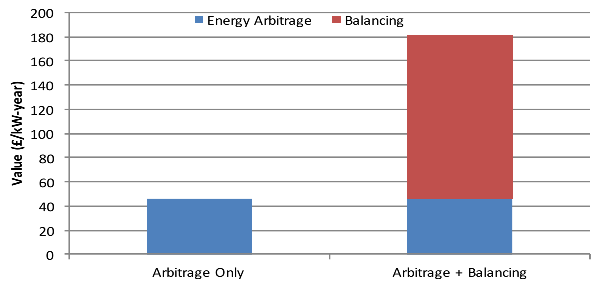

Figure 1. Value of ES for participation in energy and balancing markets

Joint operation of ES with PV farm

Another potential application of ES is to be jointly operated with a PV farm. This proposition may be attractive for two reasons. Firstly, the difficulty associated with accurate forecast of PV generation may lead to high imbalance charges faced by the PV farm. Secondly, due to the intermittent nature of PV generation, the capacity of network connection between the PV farm and the grid is normally only a fraction of the total installed capacity of PV, which inevitably leads to PV curtailment during high output conditions.

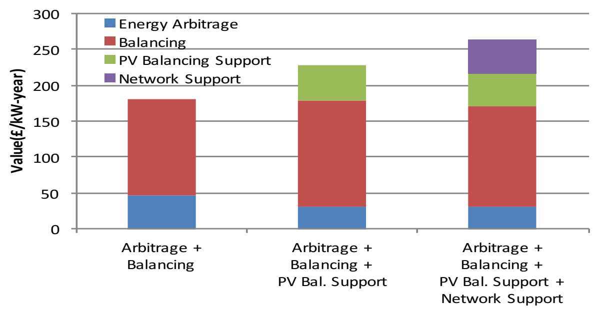

Figure 2.Value of ES under joint operation with PV farm

ES offers a potential solution to these situations, which in turn may further enhance the business case for deploying ES. Therefore, we investigate the value of a 5 MW ES that is co-located with a 20 MW PV farm in a network with 20/10 MW connection capacity with the grid. The results in Figure 2 suggest that the joint operation strategy may increase the value of ES by up to £50/kW/year through reducing the imbalance charges that PV farm is exposed to, and by another £30/kW/year through managing the limited network capacity. Furthermore, coordination between active and reactive power outputs is shown to be fundamental for an effective delivery of congestion management service. Reactive power support from ES can also support operation of ES in the balancing and energy markets and thus increase its revenues by up to 10%.

These results suggest there may be considerable added value from ES being co-located and operated in coordination with a PV farm. Providing services that would substitute for network reinforcement may be significant, while not making significant compromises in revenues associated with energy arbitrage and providing balancing services. This demonstrates that there would be significant benefits from managing synergies and conflicts between DNO and TSO services.

Frequency response provision from ES

ES could also provide FR by rapidly adjusting its charging or discharging power in response to a system frequency event. The value of ES with FR provision is assessed under two alternative market arrangements:

- *Advanced contract of FR (PFR at All Time)*. This reflects the present GB market arrangement, where the amount of FR is contracted in month ahead of real-time operation and is required to be available throughout the day for the entire contracted period.
- *Optimal FR*. This represents a more flexible arrangement, which allows the required provision of FR to be determined at the close of STPX. Under this arrangement, ES could optimise the provision of FR based on the FR prices and prices of other services.

Note that the *market design* could lead to conflicts and thus limit ES from capturing the benefits that storage could provide. As demonstrated above the system value of and need for FR varies significantly as a function of actual system conditions (level of demand and production of renewable generation). When off-peak demand coincides with high renewable production, the value of FR is very high, while there would be no need to provide network services at that time; on the other hand, during peak load conditions the value of FR is relatively low, while the need for DNO service is high, so fundamentally there should be no conflicts in ES providing frequency regulation and DNO services. However, the present long-term contract based ancillary service would prevent ES from accessing the revenues associated with providing FR (TSO service) and distribution network management services (DNO service)

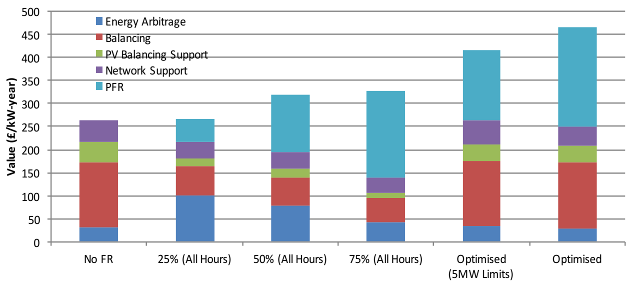

Figure 3.Value of ES with PFR provision

In studies under the present market arrangement, we assumed that 25%, 50% or 75% of the ES capacity has been exclusively allocated to FR service throughout the year. As shown in Figure 3, the results suggest that participating in the FR market would increase the overall value of ES, but at the expense of reduced revenues from other markets. The value obtained by ES increases with an increased allocation for FR, and can be up to £66/kW-year higher than in the case when no FR is provided.

The value of ES in the case of optimal FR provision is much higher than under the present market arrangement. This high value is driven by the flexibility to dynamically provide optimal amount of FR in response to different system conditions. For instance, if the prices from other markets (arbitrage, balancing) are high, the ES operator could choose to provide other services instead of FR. Conversely, during hours with high FR price, ES would choose to charge at maximum power to be able to offer up to twice of its rated power capacity to the FR market (given that the FR provision would entail not only discharging but also the interruption of charging, doubling the net effect in terms of FR provision).

Under the optimised case, the added value of FR provision is more than £210/kW/year. Even if the maximum FR provision from storage is limited to its rated capacity (5 MW), the added value still exceeds £150/kW/year. In summary, FR provision from ES would significantly increase its commercial value, but this is contingent on the future FR market arrangement adapting to enable more short-term contracting that dynamically adapts to system conditions.

Value of ES with capacity market participation

Capacity markets have recently been introduced in UK and US, to ensure adequate capacity is present to support security of supply during peak demand condition. To qualify for participating in the capacity market and obtain capacity payment, participants need to commit to provide a certain amount of energy output or demand reduction during peak hours determined by TSO over the course of a future year. Figure 4 shows the additional value of ES as the result of participation in the capacity market. It is clear that the participation in capacity market could secure upfront payment for energy storage while only slightly reducing its profit from other markets.

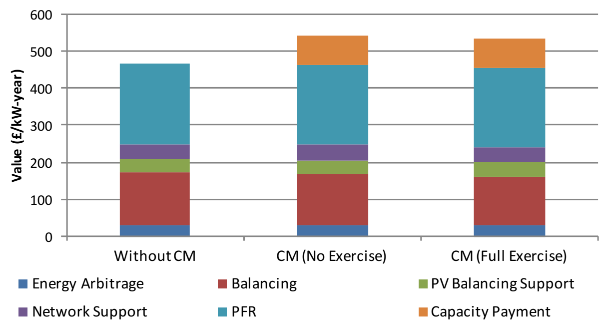

Figure 4. Value of ES with capacity market participation

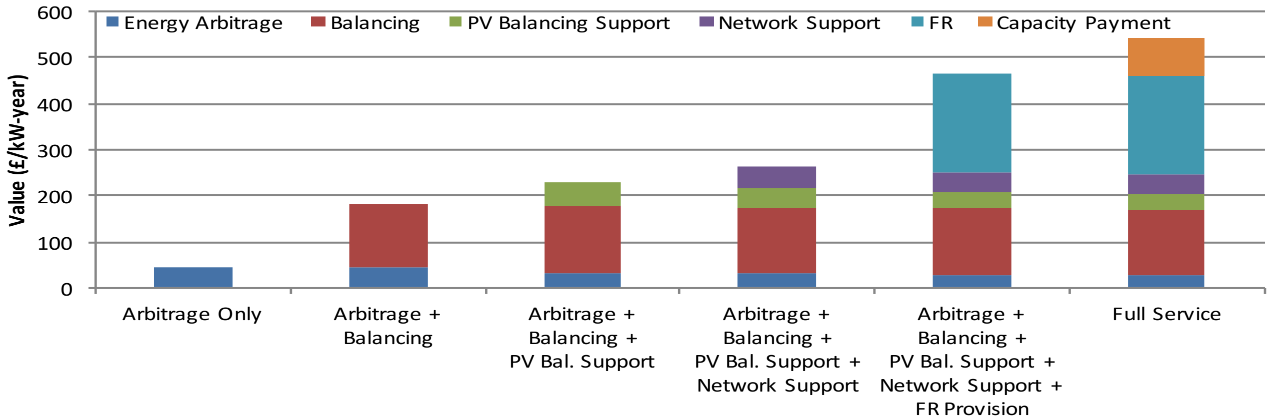

Figure 5. Value of ES with layered service provision

SUMMARY AND CONCLUSION

Figure provides a summary of the case study results looking at the commercial value of ES from layered service provision. The annual gross revenues of ES vary from £46/kW/year to £554/kW/year, depending on the range of services that storage provides simultaneously.

It is clear that the revenues from any single service can not justify the relatively high investment cost of ES. Optimised provision of multiple services is therefore the key route for ES to make a profitable business case in the market.

Specifically, our results suggest there is considerable added value from ES being co-located and operated together with a PV farm particularly when there is an active network constraint. Providing services that would substitute for network reinforcement may be significant, while simultaneously making revenues from energy arbitrage and from providing balancing services. This demonstrates that synergies between DNO and TSO services would be significant in this case. Reactive power support from ES can also support operation of ES in the balancing and energy markets and thus increase its revenues by up to 10% increment.

Furthermore, provision of frequency regulation from ES would significantly enhance its value proposition, although this would greatly depend on the frequency regulation market arrangements. Clearly, the present long-term contract based ancillary service would prevent ES from simultaneously accessing the revenues associated with providing frequency response (TSO service) and distribution network management services (DNO service) driven by need to manage demand peaks. In this context, there are very significant conflicts between provision of TSO and DNO services.

It is also important to point out that the participation in capacity market could secure upfront payment for ES while only slightly reducing its profit from other markets.

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