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Revenue Stacking: Maximising the Value of Energy Storage Services

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SUMMARY

There is increasing interest in connection of energy storage to electricity networks due to an improved understanding of the services that energy storage could potentially provide, greater requirements for load flexibility and decreasing unit costs for some technologies.

Service stacking can provide significant commercial opportunities however it is critical to evaluate technical considerations for service requirements and network characteristics. Some services are complementary to one another and others are conflicting due to factors such as charging/discharging behaviour and impact on existing network loading. Services which require responses over similar timescales will tend to cluster into a more efficient service stack offering. Some services are seen as so vital to the system operator that capacity must be partitioned, to guarantee its availability when required. However, including capacity partitioning in service contracts may significantly increase the cost of procuring the service because the energy storage provider cannot use that capacity for any other revenue streams.

In order to access these services efficiently and to appropriately monetise the value of energy storage to grid flexibility, there are number of regulatory and commercial challenges to be addressed. These relate to contract tenures which improve the certainty and bankability of energy storage facilities and the corresponding time periods for regulation of system operation for example. Also, in order to better reflect the value of the flexibility of energy storage, its treatment in network planning should depend on what service/s the energy storage facility is delivering and its corresponding charging and discharging behaviour.

Whilst we provide a UK perspective from our work in supporting energy storage developers and the Great Britain (GB) energy regulator, we consider that these key principles and recommendations are applicable to a significant extent more internationally, albeit depending on the level of market deregulation.

KEYWORDS

Energy Storage, Battery Storage, Revenue Stacking, Frequency Response, Distribution, Transmission, Constraint Management, Voltage Support

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INTRODUCTION

There are several key factors that are leading to an increased interest in connection of energy storage to electricity networks. These include;

- Improved understanding of the services that energy storage could potentially provide to a range of customers including electricity suppliers and utilities. This is resulting in greater certainty of commercial models and required technical specifications (e.g. control systems).
- Greater requirement for load flexibility within distribution networks due to increasing embedded variable generation and low carbon loads (electric vehicles, heat pumps). The deployment of energy storage to better manage and optimise network power flows in real-time can facilitate more efficient network planning and operation.
- Decreasing unit costs for energy storage technologies, as manufactured volumes increase for a range of applications e.g. electric vehicles, utility and domestic scale battery storage.

Innovation projects such as UK Power Network's Smarter Energy Storage project [1] are providing significant learning in terms of technical specifications and commercial innovation. They have found that battery storage can and should be used in multiple applications to maximise revenue streams with operating costs penalising idle storage assets [2]. The current Enhanced Frequency Response (EFR) tender for provision of fast response frequency services to National Grid, the UK transmission system operator, is well suited to the capabilities of many energy storage technologies. This has helped to really drive the market in terms of a clear commercial opportunity for developers to pursue. UK Distribution Network Operator Scottish and Southern Power Distribution Limited is aiming to assess the viability of using embedded third party assets, such as energy storage, to improve security of supply, avoid reinforcement and minimise the use of mobile generators in its ReZone Network Innovation Competition bid [3]. This should specifically provide learning for development of distribution network services.

In this paper, we explore a range of commercial opportunities for energy storage facilities and how these can be maximised by taking consideration of technical factors. We also provide recommendations on addressing related commercial and regulatory challenges that currently exist in the UK. Whilst we provide a UK perspective from our work in supporting energy storage developers and the Great Britain (GB) energy regulator, we consider that these key principles and recommendations are applicable to a significant extent more internationally, albeit depending on the level of market deregulation.

There are a number of key principles to consider when developing business models for energy storage in order to maximise revenue. Optimising a revenue stack requires consideration of interdependent commercial and technical issues. We use the following distinctions to discuss how and when services could be combined within a single business model:

- Existing revenue streams versus revenue streams that may be available in the near future (subject to regulatory and commercial changes);
- High energy (long timescale) versus high power (short timescale) services;
- Global services vs. locational services;
- The state of charge at which the energy storage facility should usually be held – does each service require the facility to import, export, or a variety of both;
- Partitioning - will the service require a partitioning of energy storage capacity.

COMMERCIAL OPPORTUNITIES

Existing Opportunities

There is currently a limited range of services in the UK suitable for energy storage revenue streams:

Energy arbitrage: This involves exploiting the price difference between electricity during daily peak and minimum demand. Many countries have large intra-day price variations. For example, prices in the UK are often much higher at peak times compared to off-peak times (between £20/MWh to £40/MWh daily difference as a quarterly average). Existing energy storage facilities take advantage of this e.g. by pumping during the night time.

Avoided network use-of-system charges/tariffs: All grid users are required to pay use-of-system charges or tariffs for the operation, maintenance and development of the networks. The tariffs depend on whether the connection is at transmission (TNUoS) or distribution (DUoS), the load type (demand, generation) and whether it is connected behind the customer meter.

TNUoS for demand is levied at the transmission interface and is also based on a regional pricing model and the average half-hourly demand during the Triads. Triads are defined as the three half hour periods (typically during winter) where demand on the transmission network is at its highest. Distribution connected storage can receive a payment from their electricity supplier if they export during Triad periods and thereby help the supplier to avoid TNUoS charges.

DUoS charges are applicable if the load is connected to the distribution network. These are calculated by distribution network operators on an annual basis using a sophisticated algorithm and may vary significantly across the network depending on locational and time-based price signals influenced by a range of factors including load profiles, losses, network capacity headroom and fault level. There is an opportunity to avoid DUoS if energy storage is located "behind the meter" to supply a local demand or generation load and effectively reduce contracted capacity connecting to the network. Also, storage may allow shifting of consumption from one time band to another. There are further revenue opportunities from DUoS credits where a non-intermittent generator is credited for MWh outputs between 4pm and 7pm in the winter.

Ancillary services to the System Operator (e.g. FFR, STOR): Firm Frequency Response (FFR) requires providers to vary their generation or demand o manage and stabilise changes in system frequency back to nominal under normal operation. There are three types of FFR: Primary and Secondary FFR have response times of within 10 seconds (sustained for 20 seconds) and within 30 seconds (and sustained for 30 minutes) respectively for underfrequency events, High FFR has a response time of within 10 seconds and sustained indefinitely for overfrequency events. The SO also distinguishes between static and dynamic responses. Minimum capacity is 10MW.

Short Term Operating Reserve (STOR) provides additional active power from generation and/or demand reduction to the system operator during times of greater than forecast demand and/or plant unavailability. In the UK, STOR providers must be able to provide at least 3 MW of capacity for at least 2 hours within 240 minutes of receiving an instruction from the SO. In the UK, large pumped hydro is currently bidding into the STOR market. These requirements make provision of STOR more attractive to energy storage technologies with high energy capabilities such as pumped storage, flow batteries, compressed air (or other gas) storage.

New Opportunities

New services that are well suited to energy storage are starting to become available:

Enhanced Frequency Response (EFR): EFR is a new service that is being tendered to improve management of system frequency pre-fault through provision of a very rapid response. It is defined by National Grid as being "frequency response that achieves 100% active power output at 1 second (or less) of registering a frequency deviation" [4]. This will enhance the capability of the system to deal with the consequences of system inertia reduction [5]. Providers of this service tender an availability payment in £/hour/MW and this is remunerated on an ex-post monthly basis depending on actual performance during that month.

Future Opportunities

A number of potential services are being actively explored by the power sector to maximise the value of energy storage in a more flexible and efficient network including:

Distribution network constraint management: In many areas of the distribution network, peak demand or generation conditions are driving costly network reinforcements i.e. new transformers and circuits. During periods of high demand or generation on a network (which are often short in duration) the energy storage facility could reduce loading by exporting or importing power, thus avoiding or deferring reinforcements. This is being investigated by a number of distribution network operators in the UK and Europe.

In a related application, in the UK the distribution network security of supply is based on Engineering Recommendation P2/6 (ER P2/6) [6]. This requires N-1 network security for voltage levels above low voltage (400V three phase in the UK) and thus, double the network capacity needed at peak loading under normal operational conditions. Unplanned outages are very infrequent so this capacity is underutilised. There is emerging evidence from modelling that storage could be used in place of conventional reinforcement to provide security of supply [7]. This would increase flexibility and result in more efficient network investment. New revenue streams could be made available in the future to support this.

Voltage support: Steady state voltage support can be provided by energy storage in the form of reactive power production or absorption. At distribution network level, this could be deployed in networks with high embedded PV uptake, for example, to reduce the impact on voltage at the ends of feeders during sunny days with low demand. There is an existing steady state reactive power service procured by National Grid, the transmission system operator, to manage the voltage profile on a local level.

Phase balancing: Phase imbalance is a significant issue at low voltage [8]. The power electronics in an energy storage converter can provide phase balancing, reducing losses, improving power quality and potentially deferring costly network reinforcement if the phase imbalance is leading to network thermal overloading or voltage issues. This provides societal benefits in terms of reducing generation requirements and thus, carbon intensive generation.

Power flow optimisation: Even where there is no existing network constraint or phase imbalance, there is value in optimising power flow on the network to reduce peaks and thus reduce network losses. In the current distribution network price control period, Ofgem, the UK energy regulator, has introduced a losses incentive mechanism which includes a licence obligation, loss reduction expenditure in the business plans, annual reporting and discretionary reward. This provides some monetisation for loss reduction although not a clear revenue stream for energy storage.

Enhanced Fault Ride Through: In the event of a network fault, the local voltage falls rapidly. National Grid state in [6] that greater post-fault transient voltage support will be required on the system in future. This is because of the reduction in synchronous generation leading to reduced fault levels. Energy storage could act as a dynamic source of transient reactive power in locations where required.

The range of potential services that energy storage could provide are summarised in Figure 1 by service application.

TECHNICAL CONSIDERATIONS

Revenue streams for energy storage can be maximised by delivering a number of services i.e. stacking services, as the business case for single services is weak in the UK at present. This is because many of these services are required on a very infrequent basis so the economics of procuring these services on an individual basis do not support the deployment of a facility with significant capital cost, relative to existing solutions/service providers.

Clearly, not all services are complementary. Specific operational and locational requirements and/or requirements for partitioning of specific capacity in the asset will limit those services that can be stacked. In order to identify a techno-economic services stack, technical feasibility and optimisation analysis should be undertaken for each development.

Energy storage services can be classified broadly as either:

- **High Power:** Services providing high power over a very short duration such as EFR;
- **High Energy:** Services provided at low to medium power over an extended duration such as management of network constraints or arbitrage.

A range of service requirements and characteristics are summarised in Table 1.

Table 1: Energy Storage Service Requirements and Characteristics

Service	Current	Future	High Power	Location specific	Constrained Network	Partitioning
EFR	✓		✓			✓
FFR	✓		✓			
STOR	✓		✓[1]			
Energy Arbitrage	✓					
Avoided Network Tariffs	✓			✓	✓	
Constraint Management		✓	✓[1]	✓	✓	**To be decided**
Voltage Support		✓		✓	✓	**To be decided**
Power Flow Optimisation		✓		✓	✓	**To be decided**
Phase Balancing		✓		✓	✓	**To be decided**

There is a potential conflict in stacking both high power and high energy services in that, in the event that high power services are required, this may subsequently leave the energy storage facility either fully charged or discharged with no flexibility to respond to a high energy service requirement. Furthermore, the choice of high power versus high energy involves many trade-offs in storage facility design e.g. inverter sizing, and indeed in the choice of storage technology. Therefore services which require responses over similar timescales will tend to cluster into a more efficient service stack offering.

Some services are seen as so vital to the system operator that capacity must be partitioned, to guarantee its availability when required. EFR services need to have capacity specifically partitioned (and metered for compliance) or risk losing their availability payment. At the times that a storage facility has declared its capacity, or a part of its capacity, available for EFR, that capacity cannot be used for any other service, even during moments when no import or export is required for EFR. For future service revenue streams, this is a condition that regulators and network operators need to carefully consider. Requiring capacity partitioning in service contracts would give the network operator greater certainty that the services will be available when needed, but may significantly increase the cost of procuring the service because the energy storage provider cannot use that capacity for any other revenue streams.

There is also a conflict in stacking services that are only suitable for a constrained network with those for an unconstrained network. For example, constraint management services could be provided to a distribution network operator to manage the locational based thermal constraints on a specific network. This could be stacked with voltage support (if required), network tariff reduction and phase balancing services. However, provision of STOR services to the system operator, although generally at highest value during winter periods, are called at unpredictable times, could exacerbate peak loading.

[1] Depends on the system or specific network (in the case of constraint management) requirements when the service is requested e.g. peak loading period may only last for a few minutes or for over two hours.

Energy storage providing EFR services are specifically required to connect to an unconstrained network.

There is also a related potential conflict between services that require energy storage to discharge e.g. EFR, constraint management for demand, versus those that require it to charge e.g. constraint management for generation, and those that require it to do both e.g. energy arbitrage.

A high level summary of possible service interactions is provided in Figure 1, where red denotes high likelihood of conflict, amber denotes possible conflict depending on specific service requirements and green denotes complementary services. Please note that for future services as denoted in Table 1, service contractual requirements are not yet known.

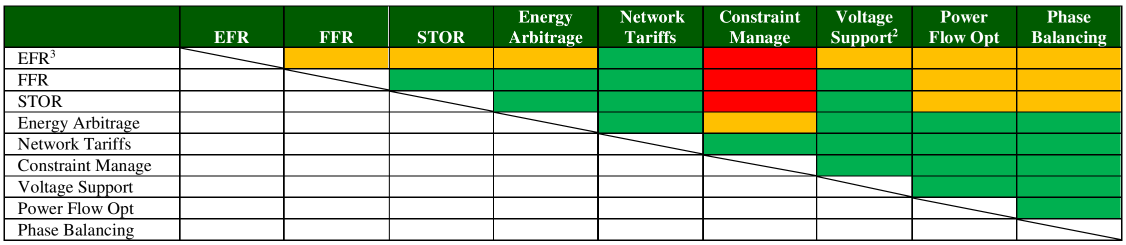

Figure 1: Guide to Revenue Stream Stacking – Avoiding Conflicts

This indicates that there is certainly significant opportunity to stack services/revenue streams. However, a well-informed choice must be made at the design stage to determine the choice of storage technology and the corresponding business plan.

REGULATORY AND COMMERCIAL CHALLENGES

Regulatory changes are required to facilitate clear and fair commercial models and give potential investors confidence in the profitability of their assets. Based on our extensive experience in the UK, key regulatory and commercial challenges are as follows;

- **Contract tenure for existing storage services:** Contracts in the most recent call by National Grid for EFR providers are only four years long. This makes it difficult to attract finance to build energy storage installations as there is uncertainty on the revenue which could be generated beyond the four-year EFR contract period. In general, many revenue streams are incompatible with long term contracts. For example, energy arbitrage would always involve the user taking a risk on dynamic pricing. Any services relating to network tariffs will be at significant commercial risk since those are only set for a year in the UK and tariff regimes are often reformed.;
- **Certainty of revenue streams**: For system operation services, this implies a move to longer price control periods. For example, the transmission system operator in Great Britain, National Grid, is currently regulated on a 2 year cycle so this limits contract length. With a longer regulatory period, it may be feasible to offer longer contracts (e.g. under DS3, EirGrid will offer 15 year contracts [9] to new build ancillary service providers). It could even be feasible to provide some form of state support, which is already available for capacity in the form of a subsidy, to better reflect the value that energy storage provides. Developing markets for future revenue streams potentially via facilitating a DNO to DSO transition is also important.;
- **Network planning standards:** There is currently no clarity on how storage should be treated in network planning standards (e.g. intermittent versus non-intermittent load, cyclical versus counter cyclical in relation to existing load patterns). This may lead to prohibitively costly

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[2] Voltage support requires provision of reactive power, which can be stacked with many other services but would usually require oversizing of the inverter.

[3] Please note that whilst EFR must be partitioned, services providers may decide to not offer EFR during periods when they can avoid network charges. Also, any non-partitioned capacity could be stacked.

grid connections if network reinforcement is deemed to be required. It also prevents the value of storage to network planners from being realised. The optimal treatment of storage in network planning is highly dependent on what service/s the energy storage facility is delivering and its corresponding charging and discharging behaviour. A review of the UK distribution network security of supply standard [7] (currently in progress) should provide some clarity.

- **Network charging regimes:** At a fundamental level, if energy storage behaves like both generation and demand, then it might be fair to charge it as both. For example, if storage triggers import and export reinforcements, then in a cost reflective system, it should pay for those. However, the emergence of storage and other Distributed Energy Resources (DER) is highlighting potential issues with how flexible demand and generation are currently treated in more nuanced charging regimes.
- **Licensing framework:** Clarification of the definition of end-user consumption in applicable regulations to exclude injections into electricity storage (e.g. to charge batteries) is required. For example, storage counts as electricity consumption when charging and thus, pays Climate Change Levy (CCL) in the UK. This could be addressed by defining Storage as a separately licensed activity (alongside generation, supply, transmission, distribution and interconnect). UK Power Networks also recommend this in [10].

Evolution to DSO

It is envisaged that in order to efficiently access services for constraint management, voltage control, phase balancing and power optimisation services at distribution level, the traditional Distribution Network Operator (DNO) role will evolve into a (Distribution) System Operator model, procuring a range of network services and interfacing with the Transmission System Operator.

This evolution would be consistent with increasingly flexible and controllable generation and demand on distribution networks and a move towards greater local control and network intelligence. However, the benefits of a DSO's transparency and independence would have to be balanced against the costs of creating a new institution, associated new infrastructure (communications, control) and any potential gaps which might arise from unbundling the distribution network [11]. The optimal approach will also depend on the level of market deregulation.

National Grid and UK Power Networks are exploring this in an innovation project [12] that aims to demonstrate a joined-up System Operator (SO) and DNO approach. Scottish and Southern Power Distribution Limited is also assessing the provision of energy storage services in its ReZone Network Innovation Competition bid [3].These should help to establish principles for procurement of a range of network services including those suitable for energy storage providers.

CONCLUSIONS

A range of existing and future services for energy storage connected to the electricity grid have been described. There is significant commercial opportunity that can be achieved through service stacking however in order to access revenues, it is critical to appreciate and evaluate a number of technical considerations relating to service requirements and network characteristics. This results in some services being complementary to one another and others in conflict. A well-informed choice based on technical feasibility and optimisation analysis must be made at the design stage to determine the choice of storage technology and the corresponding business plan.

In order to access these services efficiently and to appropriately monetise the value of energy storage to grid flexibility, there are number of regulator and commercial challenges to be addressed. These relate to the certainty and bankability of commercial contracts and the corresponding regulatory framework for system operation, utility and customer services. Network planning standards and charging regimes for use-of-system should better reflect the flexibility of energy storage with an evolution to a distribution system operator model will support further integration.

BIBLIOGRAPHY

[1] UK Power Networks. Smarter Network Storage. 2016. http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/. Accessed July 2016.

[2] UK Power Networks. Smarter Network Storage SDRC 9.7 Successful Demonstrations of Storage Value Streams. March 2016 http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/Project-Documents/SDRC+9.7+Successful+Demonstrations+of+Storage+Value+Streams+LoRes+v1.pdf.

[3] Scottish and Southern Power Distribution Limited. Electricity Network Innovation Competition Screening Submission Pro-forma. ReZone - Resilient Network Zones, 2016. https://www.ofgem.gov.uk/system/files/docs/2016/04/ssepd_nic2016_isp_rezone.pdf.

[4] National Grid. Enhanced Frequency Response. http://www2.nationalgrid.com/Enhanced-Frequency-Response.aspx. Accessed July 2016.

[5] National Grid. System Operability Framework 2015. UK Electricity Transmission. November 2015.

[6] Energy Networks Association. Engineering Recommendation P2/6. "Security of Supply" P2/6. July 2006.

[7] Imperial College London. Review of Distribution Network Security Standard. March 2015.

[8] Weatherhead S, Higgins CE, Collinson A. Characterisation of Phase Current Imbalance on Three-Phase LV Feeders To Identify Opportunities for Rebalancing. CIRED 23rd International Conference on Electricity Distribution. Lyon. June 2015.

[9] Single Electricity Market Committee. DS3 System Services Procurement Design and Emerging Thinking Decision Paper. SEM-14-108. December 2014. https://www.semcommittee.com/sites/semcommittee.com/files/media-files/SEM-14-108%20DS3%20System%20Services%20Decision%20Paper.pdf

[10] UK Power Networks. Smarter Network Storage Electricity Storage in GB: SNS 4.7 Recommendations for regulatory and legal framework (SDRC 9.5). September 2015. http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Smarter-Network-Storage-(SNS)/Project-Documents/Report+9.5+19Oct_v2.1_%28Final+Photos%29.pdf

[11] Aggarwal S, Gimon E, O'Boyle M. Trending Topics in Electricity Today – The Distribution System Operator. America's Power Plan. Accessed July 2016. http://americaspowerplan.com/2014/09/trending-topics-in-electricity-today-the-distribution-system-operator/)

[12] National Grid & UK Power Networks. Electricity Network Innovation Competition Screening Submission Pro-forma. Transmission and Distribution Interface 2.0 – TDI 2.0, 2016. https://www.ofgem.gov.uk/system/files/docs/2016/04/electricity_isp_proforma_nic_12_04_2016_final.pdf