ACTIVE NETWORK MANAGEMENT SUPPORTING ENERGY STORAGE INTEGRATION INTO SYSTEM, MARKET AND THE DISTRIBUTION NETWORK

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ABSTRACT

There has been an increase in the number of applications to connect large scale storage devices to distribution networks in the United Kingdom. Possible reasons for this include the decrease in technology cost and changes to the UK renewable policy and regulation. This introduces new complexities for how UK Distribution Network Operators (DNOs) treat the connection of storage, as it is not defined in the licenses, standards and codes of practice. Additionally, there is a question of how DNOs should model storage devices for network planning and connection into Active Network Management (ANM) schemes.

This paper discusses and analyses the approach a DNO could take in managing energy storage using ANM within the existing framework of constraint management (e.g. rules based Principles of Access such as LIFO and Shared) and the revenue streams available in the existing energy, balancing and ancillary services markets in the UK. While these are not entirely new arrangements (a number of distributed generators already operate as system Balancing Mechanism Units in the UK), one challenge anticipated is the ability to provide services to transmission system operators in a constrained area of the distribution network.

INTRODUCTION

Distribution Network Operators (DNOs) have increasing interest in maximising utilisation of assets through alternative connection solutions to improve cost efficiency and maintain security of supply.

There is also growing interest in large scale energy storage deployments following the decrease in technology cost and changes to UK renewable policy and regulation. Energy storage systems are not currently considered in the current planning standard for distribution networks. As energy storage can act as both load and generation, it is vital to assess its contribution to enabling low carbon economy and security of supply.

Active Network Management (ANM) involves the real-time management of power producing or consuming devices within the thermal or voltage constraints of the network. ANM can be applied to both transmission and distribution networks and forms a major component of the future smarter grid. Under ANM deployments to date in the UK, energy storage devices can be offered a Managed (or non-firm) Connection where their output will be adjusted according to network conditions. Managed connection of energy storage using an ANM solution will be different to other conventional distributed energy resources due to the presence of both power and energy constraints and their dependence on the state-of-charge.

ANM solutions are becoming business as usual for the majority of UK DNOs [1], and managed connections can now be offered as standard alongside the more conventional, firm connection offers [2]. Developers choose ANM connections because they can connect at a lower cost, and in a shorter time frame when compared with conventional connection offers. This has been demonstrated across a number of schemes in the UK, including UKPN’s Flexible Plug and Play project [3] which saved £38m in connection charges for participating customers. This paper discusses how DNOs might choose to treat storage devices connecting to the network, for both firm and managed connections. It explains how the DNO could model energy storage whilst considering:

- Charge/discharge of the device is typically dominated by energy market & ancillary services market and not by available resource or the local distribution network state.
- Services that energy storage could offer to the DNO such as providing operational flexibility and improving congestion management.

General modelling requirements and possible assumptions for the integration of energy storage into ANM schemes are provided. UK Power Networks’ learning to date from the Smarter Network Storage project is also presented.

BENEFITS OF ENERGY STORAGE TO THE DISTRIBUTION NETWORK

Energy storage can offer a variety of grid services to DNOs such as peak demand reduction, network constraint management and voltage management.

Peak demand reduction

Energy storage has the capability to provide fast response and emission-free operation, making it a valuable solution for peak demand reduction. Peak shaving operation attempts to reduce the demand peak via demand side response or by offsetting the demand by supplying power locally through distributed generation or energy storage.

Absorption of generation output

Energy storage can be controlled and scheduled to import energy during network congestion periods, reducing the required curtailment of DG. The ANM system can monitor constraint locations on the network as well as the metering circuit breakers that connect the generators to the distribution network. When a constraint threshold is reached with an excessive level of power flow then the ANM sends either a trim or trip instruction to the lowest priority DG in the 'stack'. Energy storage can be issued with an instruction to import (charge) up to its full rated capacity, or the highest capable import level if full rated import is not feasible. This way the network thermal constraints are not breached and DG will be subject to lower levels of curtailment [5]. Currently there are limited opportunities for DNOs to contract such services with the only advantage provided by increasing the number of customers and thus increasing Distribution Use of System revenues (DUoS).

Voltage management

In its simplest form, energy storage devices can be instructed to operate in an export mode, injecting real power into the distribution network to increase the voltage at the remote end of a circuit. The capabilities of power electronic interfaces might also play a useful role.

OVERVIEW OF STORAGE BUSINESS MODELS IN THE UK MARKET

Based on the regulations in the UK, DNOs are not permitted to own generation licences. Currently energy storage is classed as a generator, hence DNOs are not permitted to own large scale storage requiring a generation licence, or trade directly in the energy markets. However, DNOs can own a battery device, but the money they can make on it is limited [6]. Energy storage can provide other types of services to Transmission System Operator (TSO) such as STOR, Firm Frequency Response (FFR) and Triad. With the exception of frequency response services (that can contracted for import, export or both), these business models are oriented for power export. To become economically viable, storage projects may need to operate in additional markets such as Ancillary Services market managed by the TSO. This market covers various activities including:

- Arbitrage on system imbalance prices based on forecasts
- Frequency response
- Short Term Operating Reserve (STOR)
- Avoiding TNUoS customer capacity charges (demand/generation)

Short-Term Operating Reserve

STOR [4] is critical when reserve power in the form of either generation or demand reduction is needed to be able to deal with actual demand being greater than forecast demand and/or plant unavailability. In other words, STOR services are offered to TSOs to provide energy in times of likely shortfalls.

Energy storage devices can be linked to the Energy Balancing System (EBS) to provide the necessary power ramps and energy import/export when requirements occur.

Triad

Energy storage developers are interested in exploiting TRIAD periods which has historically occurred during the 16:00-18:30 window in winter. Within these periods, a significant proportion of the annual network use charges are imposed by the TSO. Triad is not a commercial service as such, but it does represent an opportunity for significant revenues from the energy storage developers. Energy storage can generate significant revenue by reducing the cost to the energy supply company and receive an agreed proportion of the saving through providing energy during the Triad periods [7].

Frequency Services

National Grid uses generation output in the Balancing Mechanism (BM) to respond to frequency variation. Other control mechanisms include management of interconnector flows and a wide range of demand side response:

- These products are used to cater for increases in demand (primary response) and decreases in demand (high response);
- Those needed after an initial imbalance and required to fully recover the system frequency (secondary response).

The cost of conventional methods to maintain frequency close to 50Hz ± 0.5Hz is estimated at £200m-£250m. This cost is based on the Gone Green Future Energy Scenario as published by National Grid in 2014, giving rise to an increase in Rate of Change of Frequency (RoCoF) of 0.3Hz/s [8].

The increasing penetration of asynchronous generation and the decommissioning of old synchronous power stations contribute to reduction in total system inertia. New tools and methods are needed to manage demand side response and energy storage to enhance frequency control capability through providing rapid frequency response. Delivery of rapid (up to 5s) power injection/reduction from the distribution system is one method that could help to reduce the generation and demand imbalance, helping with frequency containment and response.

ANM could again provide the means of accessing these fast acting power injection/reduction devices in distribution networks to increase system inertia.

Enhanced Frequency Response (EFR)

A new service that has been recently announced by the TSO in the UK is EFR; it is in essence a dynamic frequency response form that achieves full (i.e. 100%)

active power output at 1 second (or less) of registering a frequency deviation higher than 0.2Hz. This new service is developed to improve management of frequency pre-fault [9] and is specifically targeted at storage and interconnectors.

ENERGY STORAGE ANM INTEGRATION MODELLING ASSUMPTIONS

When deploying ANM systems, it is necessary to define the available capacity and the levels of curtailment a managed generator might experience. This allows generation developers to assess the economic feasibility of connecting to a constrained network.

Several UK DNOs are rolling out ANM systems in their networks as a solution to heavily constrained circuits. This section provides some general modelling requirements and possible assumptions to guide the modelling of integration of energy storage into ANM schemes. It is important to emphasise that modelling is closely linked to ANM system requirements and design which is critical for implementation into DNO systems. General energy storage modelling considerations include:

- How the energy storage developer intends to use the battery. This will have the most impact on the network operation e.g. if they all want to participate in STOR or TRIAD, then all energy storage devices may be required to export at the same point in time and may also then be in charge or float states simultaneously too.
- Assuming 'always on' (AO) for an energy storage would be a conservative approach assuming a full discharge and charge cycle throughout the day. However, with multiple storage devices on the network, this would not account for possible variations in charge/discharge cycles between the different devices. The only consideration given is to the export of the battery, as this is when generation export constraints will apply. If the battery is charging, then it simply creates more headroom on the network and this does not need to be considered in the curtailment assessment i.e. assume there is no charging, and therefore no benefit.
- A Last In First Off (LIFO) curtailment model is best suited to an ANM stack with storage devices as it allows a clearer understanding of availability to provide services. The storage device at the top of the stack will likely have no limitations on when they can import or export, those further down the stack, with a lower priority, may have restrictions on export/import and therefore have limitations on what services they can provide [10].
- It should be recognised that the preferred output reporting from a curtailment assessment will be different from that required for a generator. A storage operator is likely to be more interested in when the site export will be limited through the year, and the available export capacity when restricted, rather than a volume of curtailed export (based upon AO or export/import profile assumptions).

Key inputs to curtailment assessments with storage include:

- Existing demand and generation on the network.
- Type of constraints and locations in ANM scheme.
- Limits/thresholds of the network constraint.
- Operational restrictions to prolong the lifetime of the storage device.
- Commercial ownership and objective of the energy storage system.
- Energy storage pairing with generator and for what purpose.
- Nature of any energy storage contracts to support the network.
- Profile of energy storage operation (import/export/float) to establish modelling assumptions (e.g. always on output or an assumed profile based on knowledge of demand peaks).

At the current time, the most profitable revenue stream from storage operation is frequency response. Provided that the operational profile of a storage device that offers frequency response is uncertain as it depends on the varying grid frequency, storage developers require the maximum possible capacity in the network to ensure maximization of their revenues.

The objective is to realistically model the energy storage without being over-conservative. Therefore, those sites with PV and Storage are modelled with a single profile (i.e. where the PV capacity is higher than the storage capacity). The combined profile of PV and storage is assumed to be always positive (i.e. exporting). The profile does not consist of negative values to model the energy storage charging behaviour. Instead, the energy storage charging has been embedded in the profile by assuming the PV would charge the battery directly.

The assumption is made that developers are interested in capturing TRIAD periods with the battery (16:00 to 18:30) between November and February. Hence 1.0 per unit (P.U.) export is assumed from combined PV and storage system in those hours. A minimum combined export of 0.5 P.U, has been assumed so that the energy export of the PV and Storage are not subject to over- curtailment. This avoids artificially overestimating the curtailment figures for customers behind in the queue.

UK POWER NETWORKS EXPERIENCE

The Smarter Network Storage (SNS) project of UK Power Networks has seen the design, development and trialling of a 6MW/10MWh battery energy storage system that serves a multi-purpose application in the electricity system.

The primary aim of the battery system which is connected at Leighton Buzzard primary substation is to defer network reinforcement by providing peak load shaving during periods of congestion. These periods occur during evening times from October-March leaving the remainder of the year available for the storage to provide other services and support the transmission network, while gaining revenue from such services provision to improve the business case for storage which would otherwise not be justified compared to traditional network reinforcement.

A number of trials have been realised in the SNS project that have provided valuable learning for the industry with respect to the contribution of battery storage systems to network operation as well as the demonstration of value streams from the operation of storage.

Trial results have indicated that battery systems are suitable and effective in providing a range of applications to electricity networks. It has been shown that:

- Synergies between different applications exist, specifically when storage systems export energy during specific periods in a year that contribute to the relief of peak load in the local distribution network and to the transmission network.
- Reactive power capability of battery storage systems may be used for power factor improvement and voltage support in the local distribution network. Reactive power can be used in parallel with other services and can contribute to peak load shaving.
- Forecasting the power and energy requirements for the delivery of each service is an important function for the maximisation of benefits from the operation of storage systems.

The SNS project has not directly investigated the application of storage systems in DG curtailment reduction as battery installation has been in a load dominated area and its primary aim has been to defer load related reinforcement.

However significant learnings from the SNS project have been gained and can be used to inform the design and operation of ANM systems with storage. These include:

- Battery systems have very fast response times and may sustain their output for long periods depending on the storage tank capacity.
- 4-quadrant power conversion systems may use their active and reactive power independently. Reactive power support can be provided indefinitely without noticeable impact on the battery performance.
- The efficiency of battery charging and discharging depends on the power drawn and the State of Charge (SoC) range. However high round-trip efficiencies have been experienced in the range of 85-95%.
- Consideration of fixed operational costs (such as auxiliary supplies and system supplier fees) and variable operational costs (such as energy prices, distribution network charges and transmission network charges) is required to assess and operate optimally a storage system from an economic viewpoint.

CONCLUSION

Storage technologies can offer valuable services to both DNOs and TSOs. An ANM system controlling distributed energy resources including energy storage could significantly reduce the system operation cost at distribution/transmission level and ultimately reduce the consumer's electricity bill, increase energy safety and security and facilitate economic connection of renewable resources. Several practical steps forward and required next steps to fully exploit energy storage integration into distribution networks have been reported in this paper.

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