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ENERGY SYSTEMS TOOLKIT

Electrical Energy Storage Module

Ricardo Energy & Environment

LOCAL ENERGY SCOTLAND

HIE Highlands and Islands Enterprise
Iomairt na Gàidhealtachd 's nan Eilean

BACKGROUND

The Energy Systems Toolkit (the 'Toolkit') is aimed at organisations, community groups or businesses, at different stages in the project development process, whether exploring ideas to develop into a project or additional options to include in a current project. The Toolkit aims to provide further information to organisations on energy systems topics that will help determining whether a project idea is viable or highlight alternative options that should be considered. The Toolkit also provides support through the development process to construction, highlighting any support available to them. This could include:

- Signposting businesses or communities to additional support (technical or financial) in developing their project, to potential project partners or to potential sources of funding;
- Provide detail on key considerations and barriers across different technology projects; or
- Highlight different technology projects and themes that have been developed successfully across Scotland.

For each of the topics, the guidance provided will be informative and will indicate the actions to be taken and the next steps the organisations should take to progress.

The Toolkit links to other relevant guidance documents, such as the CARES Toolkit, which can be used in parallel.

INTRODUCTION TO ELECTRICAL ENERGY STORAGE

Electrical energy storage can provide a range of grid support services that can help maintain a stable and reliable electricity supply. Working in tandem with smart grid technology, the functions that it can provide include:

- Enabling the integration of more renewables into the energy mix.
- Storing energy from renewables to smooth variable supply.
- Helping energy consumers to manage their energy demand.
- Stabilising voltage and frequency on power networks.
- Deferring grid infrastructure upgrades.
- Secure and resilient energy supplies during power outages.

Due to the fact that electrical energy storage systems permit higher levels of intermittent renewable generation on constrained distribution infrastructure, it can help overcome the barriers to connecting new renewable energy projects.

The module will provide insight into the roles that electrical energy storage can play, the most commercially advanced storage technologies and outlook. It is aimed at organisations with both development stage and operational schemes.

There are of course other types of energy storage, not just electrical. Thermal storage has been used in a number of projects where constrained power is used to generate heat that is supplied to nearby buildings. This innovative solution requires a different approach to electrical energy storage and is not explored in detail here.

Roles for energy storage

Electrical energy storage is flexible and can deliver a wide range of grid support services, and can potentially deliver several of these at the same time, known as 'value stacking'. The key contexts and functions are:

- **Network support:** Distribution network operators can use storage to manage grid constraints and defer larger investments in new infrastructure. This could be combined with voltage and frequency control.
- **Behind the meter:** Industrial and other large consumers of electricity can use storage to reduce peak demand, in-support of on-site generators and to increase supply resilience. Domestic: Home energy storage systems are also available and can work in tandem with microgeneration.
- **Alongside renewables:** wind and solar farm operators can add storage to manage intermittent output and deliver grid services like frequency response.

All of these services are especially valuable on weak and island grids, where the need to balance supply and demand locally is critical.

THE MARKET FOR ELECTRICAL ENERGY STORAGE

Growing demand for electrical energy storage has created a virtuous combination of increasing investment in technology and production at ever-larger scales. As a result, the cost of large grid-scale batteries is falling dramatically and is experiencing the same transformational learning effects witnessed with flat screen TVs, solar panels and LED lighting.

While, energy storage is expected to be able to deliver these services cost-effectively, it is important to stress that this is not yet the case. Prices need to continue falling and a comprehensive framework of regulation for storage still needs to be put in place. As a result, new storage capacity is benefiting from early stage funding via premium markets, like Enhanced Frequency Response which is described below, and grants for technology demonstration.

There are already many electrical energy storage projects in the UK. In all, 3.2GW worth of capacity across a wide range of storage technologies are operating, from large pumped hydro schemes developed in the 1960s to large grid connected lithium ion batteries installed in 2016[1]. There are many more projects at the planning and development stage, including 200MW of Enhanced Frequency Response projects (see the section on page 7).

National Grid's Future Energy Scenarios[2] are the grid operator's long term plans for how the power system will develop. The latest 2016 edition now includes energy storage for the first time. They believe that energy storage could be 'a significant contributor to meeting system flexibility needs' by 2025, with several gigawatts of new energy storage capacity potentially installed.

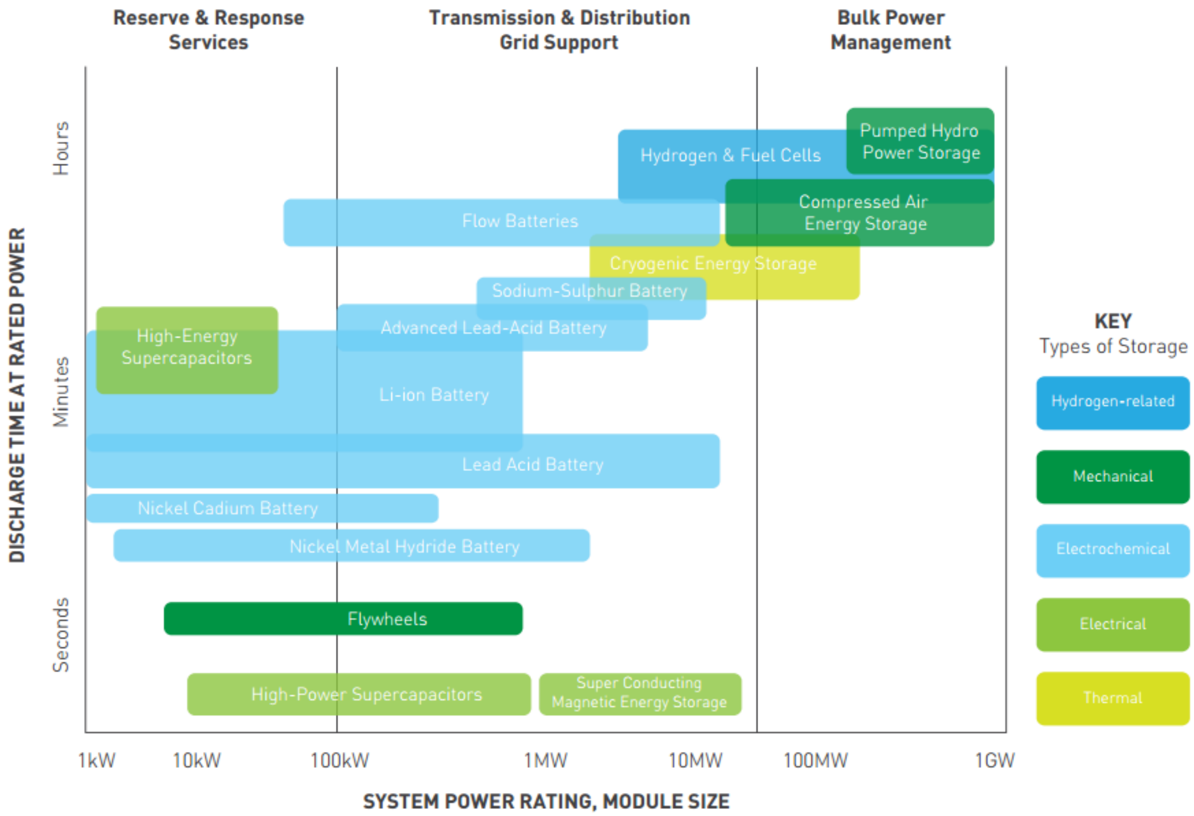
A government-backed report by the Carbon Trust[3] and Imperial College London suggests the cost of the UK's energy system could be reduced by up to £7 billion each year where energy storage is combined with smart grids and demand flexibility.

ELECTRICAL STORAGE TECHNOLOGIES

There are a wide range of energy storage technologies, each suited to different applications depending on their characteristics, such as power rating, discharge rate and cost. Some are more suited to providing power for short periods of time (i.e. balancing the frequency of the grid with lithium-ion batteries) and others are better at storing energy for longer periods (i.e. storing solar

[1] Energy Storage in the UK: An Overview, The Renewable Energy Association, 2016
[2] National Grid (2016) Future Energy Scenarios http://fes.nationalgrid.com/
[3] Carbon Trust (2016) Can storage help reduce the cost of a future UK electricity system? https://www.carbontrust.com/media/672486/energy-storage-report.pdf

generation for nighttime discharge with flow batteries). The graphic below presents a comparative overview of many electricity storage technologies.



Energy Storage Technologies compared, the University of Strathclyde[4]

The capacity of a battery is typically described by the amount of energy it can store in kilowatt-hours (kWh) and its maximum power output in kilowatts (kW). The discharge rate of the battery is the amount of power (in Watts) that it can deliver. The discharge time is the length of time it can sustain its maximum discharge rate which is determined by how much energy it can store.

Lead Acid Batteries

Lead acid and sodium sulphur batteries have been installed on island grids in the past decade. There is a current demonstration project using Tesla lead acid batteries Lead acid batteries are the oldest type of rechargeable battery and can supply high surge currents and have in the past been a least cost storage technology. However, they are large and heavy for the amount of energy they can store. More recently grid-scale lithium ion systems have emerged alongside redox flow batteries as alternatives.

Other promising, but less mature storage technologies are being commercialized, including vanadium redox flow and organic flow batteries. Some energy storage technologies are more advanced than others, and the state of technology development and commercialisation needs to be weighed against its suitability for the role. We focus on those technologies being used to add new storage capacity to the grid:

[4] More information about the battery technologies included in this graphic can be found on the University of Strathclyde website: http://www.esru.strath.ac.uk/EandE/Web_sites/14-15/Industrial_autonomy/2_1_technology_options.html

Lithium-ion batteries

Lithium-ion batteries are a key component of mobile devices and electric cars. Scaled-up static lithium-ion batteries are beginning to be used to provide grid services because they can hold multiple megawatt hours of power and can discharge it quickly. Lithium-ion based systems are commercially available from a number of suppliers in a price competitive market. A typical grid-scale lithium battery system is housed in one or more shipping container such as the example below.

Grid-scale lithium-ion batteries are typically housed in shipping containers.

Inside the container lithium-ion batteries are stored in racks similar to those you would find in a computer server room. The majority of lithium-ion batteries consist of aluminium anodes and copper cathode, although other materials are being researched. The lithium-ions within the electrolyte are generally lithium manganese oxide or lithium cobalt oxide, moving through an organic solution as the batteries are charged and discharged.

Lithium-ion batteries have high energy density and can be cycled – charged and discharged – rapidly (needed for applications such as frequency response) or slowly (e.g. to power a mini grid when renewable output is low). This makes them flexible and able to provide a range of different services all at once. The capacity of the battery gradually degrades overtime, with regular and deep cycling increasing the speed of aging. As a result, the useful lifetime for lithium-ion batteries varies from 5 to 15 years.

Users should dispose of their batteries in an environmentally sound way. For example, the disposal of whole, untreated and industrial and automotive batteries in landfill or by incineration is banned. Guidance is available from NetRegs as to how end users can recycle or dispose of waste batteries.[5]

Lithium-ion battery technology is being used in the majority of new and planned grid-scale energy storage projects. Over 1GW of lithium-ion projects are at the early stages of development with at least 200MW now progressing to construction in the UK following the Enhanced Frequency Response auction.

[5] http://www.netregs.org.uk/environmental-topics/materials-fuels-and-equipment/batteries-regulations/

***Case study: Storage + solar + grid - lithium-ion providing flexible services*[6]**

RES, the renewable energy developer, is installing a 248kW/640kWh lithium-ion battery alongside its existing 1.5MW solar park at Copley Wood in Somerset.

The innovative trial has the support of National Grid and will connect to Western Power Distribution's network in order to provide grid-support services. The battery will shift the solar power generated during the day and will help to manage constraints on the network.

RES are providing a "one-stop shop" service, designing, installing and operating the battery under a single contract. RES will remain in control, telling it when to charge and discharge.

Smaller scale domestic lithium-ion batteries are available as well. A demonstration project of domestic lithium-ion batteries is currently underway in Orkney[7], with the batteries connected to solar panels on the properties aiming to store enough electricity for the households, whilst potentially alleviating grid constraints across the island to all increasing renewable generation.

Redox flow batteries

Redox flow batteries have similar electrochemistry to conventional lead acid batteries. The difference is found in the storage of energy in electrolytes in large external tanks. The liquid electrolyte flows through the battery meet at the membrane, converting chemical energy into electricity during discharge.

Vanadium based redox flow batteries are of particular interest because they are claimed to hold capacity for longer than lithium-ion, extending its useful lifetime. They are suited to delivering 100kW to 10MW over 2-8 hours duration[8]. This means they are able to provide support services to renewables and mini-grids for example. Vanadium solutions are not flammable, reducing safety concerns.

The cost of vanadium redox flow batteries is falling as the technology is trialed and commercialised.

***Case study: Knoydart community electricity grid*[9]**

Knoydart is an off-grid community that is powered by a small hydro plant and a diesel generator that operates during peak hours. Increasing demand means the diesel generator is running more often and they sometimes experience blackouts whilst the hydro is underutilised when demand is low.

The community is planning on installing a flow battery energy storage system. It would be used to store hydro power at night for use during peak times. It would be controlled by an intelligent micro grid control system, balancing supply and demand automatically, and would allow the diesel generator to be removed.

As part of this feasibility study, a detailed analysis of the Knoydart power generation and distribution system was developed and a prototype flow battery was used to simulate operation. The study indicates that it would reduce the cost of electricity, improve the stability of the power supply and reduce carbon emissions.

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[6] www.imeche.org/news/news-article/renewable-energy-systems-confirms-first-uk-battery-energy-storage-project

[7] https://m.facebook.com/story.php?story_fbid=1349345505111366&substory_index=0&id=161154750597120

[8] http://energystorage.org/energy-storage/technologies/vanadium-redox-vrb-flow-batteries

[9] More information is available at http://www.localenergyscotland.org/funding-resources/funding/local-energy-challenge-fund/development-projects/development-projects-2015/ensuring-future-energy-security-for-knoydart/

POLICY AND REGULATION

Energy storage capacity is growing at a remarkable pace and is expected to become an established part of the energy system over the coming years. Projects coming forward so far are doing so in advance of a complete regulatory framework. At present, storage is not fully recognised in electricity distribution network rules and standards.

In response, the government are developing policies for energy storage. A call for evidence was published in November 2016. *Towards a Smart, Flexible Energy System*[10] suggests that barriers to energy storage will be reduced and it will be recognised in regulation. The policies being considered aim to create a level playing field for sources of grid flexibility.

The Scottish Government is preparing a new, over-arching Energy Strategy. It intends to respond to a number of drivers of change, including shifts in UK Government policy, new devolved powers and Scotland's strengthened ambition to tackle climate change. It will also be an opportunity to take advantage of new innovation, including energy storage. It is anticipated that the draft Energy Strategy will be published in early 2017 for public consultation.

Enhanced Frequency Response

Frequency response services help maintain grid stability by holding the system frequency within a narrow band either side of 50Hz. As the penetration of renewable energy into the grid increases and the capacity of large thermal generation decreases, the overall 'inertia' of the generators connected to the system falls, making it more susceptible to sudden changes in load and therefore changes in frequency.

National Grid is increasingly in need of frequency services that can respond rapidly. Enhanced Frequency Response (EFR) is a new market which is designed to activate in one second or less. Lithium-ion batteries are one of the few technologies which can deliver this fast and sustained response.

This is a new market and the first auction resulted in 200MW of capacity being procured, most of which was large multi-MW lithium-ion batteries, many of which will be installed alongside wind and solar farms. While it is unlikely that community projects will enter the EFR market, it is indicative of the fast pace of market developments and the type of revenue streams that could become more prevalent in future.

The EFR market is seen as a significant milestone as it marks the emergence of UK expertise, an indicator of how far the price of grid-scale storage has already fallen. National Grid has stated their intention to hold regular auctions 'over the next 10 to 20 years' but details are not confirmed. It is also viewed as an important revenue stream for battery developers because this new market has been designed specifically for energy storage and is kick-starting the industry in the UK.

Suitable sites for frequency response can be located anywhere on the GB grid, the key issue is a site for secure dual circuit grid connection. For other ancillary services National Grid have a preference for capacity nearer to the large demand centers in England.

The EFR market technical requirements include:

- Minimum battery capacity of 1MW (smaller batteries can participate through aggregators, though none were successful in the 1st auction).
- Able to respond in less than one second. Minimum duration of 9 seconds.

[10] https://www.gov.uk/government/consultations/call-for-evidence-a-smart-flexible-energy-system

- Revenue based on an availability fee (£/hr) and a utilisation payment (£/MW/hr)
- The storage systems could potentially also be used to deliver other grid balancing services.

SUMMARY

Electrical energy storage is an enabling technology which can help create a smarter more flexible power system. It will be play an increasing role in decarbonising the electricity supply.

For small and community-led energy projects electrical energy storage can:

- Increase output from renewable energy projects with constrained grid connections.
- Speed up the connection process in grid constrained areas, potentially at lower cost.
- Maintain grid stability by smoothing variable output on island or weak grids where interconnection is limited.
- Earn additional revenue from installing electrical energy storage alongside a renewable energy project to deliver ancillary services.

The increasing opportunities from electrical energy storage are evident. However further cost reduction, along with development of policy and regulation, are needed in order for its full potential to be achieved over the next 5 or 10 years. In the meantime community-led and small energy project developers considering storage will need to progress with care, ensuring that storage does not have a negative effect on grid, planning, liability and incentive agreements while regulatory uncertainty remains.

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