Report on Grid support batteries in the UK Rev 1 - July 2017

Introduction

Department for Business, Energy and Industrial Strategy (BEIS)/Department of Energy and Climate Change (DECC)
has identified energy storage as a key priority. They announced the first phase of a £246 million investment in battery technology by launching the ‘Faraday Challenge’. The first phase includes the launch of a £45 million ‘Battery Institute’ competition to establish a centre for battery research to make technology more accessible and affordable

Known as the Faraday Challenge, the 4-year investment round is a key part of the government’s Industrial Strategy. It will deliver a coordinated programme of competitions that will aim to boost both the research and development of expertise in battery technology.

Preamble - An overview of different storage technologies

Pump hydroelectric storage

This is the oldest technology for the storage of electricity, having been first deployed in the 1920’s. It works by storing energy in the form of water in the higher of two reservoirs, to where it is pumped from the lower reservoir during periods when the plant is not in use. When electricity demand is high, power is generated by releasing the water through turbines. When demand and electricity prices are low the upper reservoir is replenished by using electricity to pump water back to the higher reservoir. Its fast response means that it is very useful for responding to system frequency deviations. Pump hydro storage has typical efficiencies of around 70-80%.

The technology is fully-proven, and the resource through which energy is stored (water) is highly abundant. However there are a limited number of suitable sites for projects in the UK, since the need for an altitude differential between the two lakes limits it to mountainous locations such as the Scottish Highlands or Snowdonia. Such sites are far from UK centres of energy demand, meaning that there are likely to be significant costs involved in connecting projects to the grid.

An innovation that may widen the number of sites where pump hydro storage can be deployed is seawater pump storage, where the sea acts as the lower ‘lake’ from which water is pumped up from and released into. There is currently one seawater pump hydro project that is operational, in Okinawa Island, Japan.

Pump hydro storage has the highest capacity of known and tested storage technologies. The four existing projects in the UK range in size from 300MW to 1,700MW see below:

(1) Dinorwig, commissioned in 1984 - 1,728 MW

(2) Foyers, commissioned in 1975 - 305 MW

(3) Cruachan commissioned in 1965 - 440 MW

(4) Ffestiniog commissioned in 1963 – 360 MW

Compressed air energy storage (CAES)

In a CAES plant, air is stored under pressure during periods of low demand/electricity prices. The storage unit is typically an underground cavern, although ground-level storage can also be used. When there is high demand for electricity, the compressed air is released, and decompresses in a turbine driving a power generator. Underground storage systems can store greater amounts of energy (up to 10MGWh). There are currently two operational CAES systems worldwide, one in the USA and the other in Germany. Due to the low storage density of air, storage facilities need to be very large. Salt caverns are ideal for this purpose, as they are flexible, with no risk of loss of pressure in the storage, or of any reaction with the oxygen in the air or in the host rock. In CAES systems, the compression of air results in very high temperatures, which have to be extracted during the compression process using coolers.

Lithium-based batteries

Lithium-ion batteries first came on the market in the early 1990's, when they were used predominantly in consumer applications. Since then they have been developed for use in a wide range of storage applications, ranging from batteries to store energy from household solar installations to larger batteries capable of providing grid ancillary services, as well as electric vehicles.

Lithium-based batteries encompass a wide range of sub-chemistries, each with specific operational and performance characteristics. Lithium-ion cells are built into multi-cell modules, which are then connected to form a battery string at the required voltage. This makes them scalable and can therefore be used in very small systems such as car and household applications right up to grid scale (MW) applications.

Flow-type batteries (including Redox)

Flow-type batteries accumulate and deliver energy via reversible electrolyte reactions, which are stored in separate tanks. In flow-type batteries, power is determined by the number of cells and their size, while capacity depends on the volume and concentration of the electrolyte. Various electrolyte ‘couples’ are possible, although currently only Zinc/Bromine and all-vanadium batteries have reached commercialisation. Zinc bromine batteries can be combined into large modules capable of storing up to 500kWh, while all-vanadium batteries can be up scaled into modules than can store up to 400kWh.

The ‘decoupling’ of power and capacity means flow type batteries are extremely flexible and can be tailored to complement the characteristics of a particular generating asset. They are suitable for use at a wide variety of scales, from storage requirements of around 500kWh up to hundreds of MWh.

Aqueous, sealed batteries

This type of battery offers high energy outputs compared to other battery technologies, potentially making it more suitable for energy arbitrage applications than ancillary services. It can help shift load from peaks to troughs through wholesale markets as renewable electricity generation increases as a percentage of the generation mix.These are designed to deliver power in typically 4 - 6 hours, so a 10MW battery would have a 40-60MWh energy storage capacity.

Cryogenic energy storage (CES)

Cryogenic energy storage (CES) stores liquefied air or liquid nitrogen at atmospheric pressure. CES has three core processes. Firstly, charging takes place when demand/prices are low, as electricity is used to drive an air liquefier. The gas is then cleaned, compressed and cooled until it is converted to liquid. It is then stored in an insulated tank at low pressure. When demand/prices are high, the liquid is pumped to high pressure, and then heat is applied, transforming the liquid to a high-pressure gas used to drive a turbine generator. Although the overall CES system is novel, the individual technologies that comprise it are already used extensively in other sectors, particularly the air separation industry that uses identical equipment. The liquid storage units required are already used for bulk LNG, oxygen and nitrogen storage, and at large scale (a 200,000t tank would be capable of storing 10GWh of electricity). This makes it a technology that could provide grid-scale solutions.

Hydrogen energy storage (HES)

Hydrogen is produced in large quantities (around 55 million tonnes per year worldwide). Some of this is so-called ‘brown’ hydrogen (derived from hydrocarbons) although an increasing amount of ‘green’ hydrogen is being produced through water electrolysis. HES works by using electrolysis to convert electricity at times of low prices/demand into hydrogen. The hydrogen can then be re-electrified using fuel cells, or burned in Combined Cycle Gas Turbine (CCGT) power stations. Although efficiencies for this process are currently low at around 30 - 40%, hydrogen offers much higher storage potential than other technologies. For example, a storage facility of 500,000 metres cubed could store up to 167GWh of hydrogen, equivalent to 100GWh of electricity.

Pumped heat electrical energy storage (PHEES)

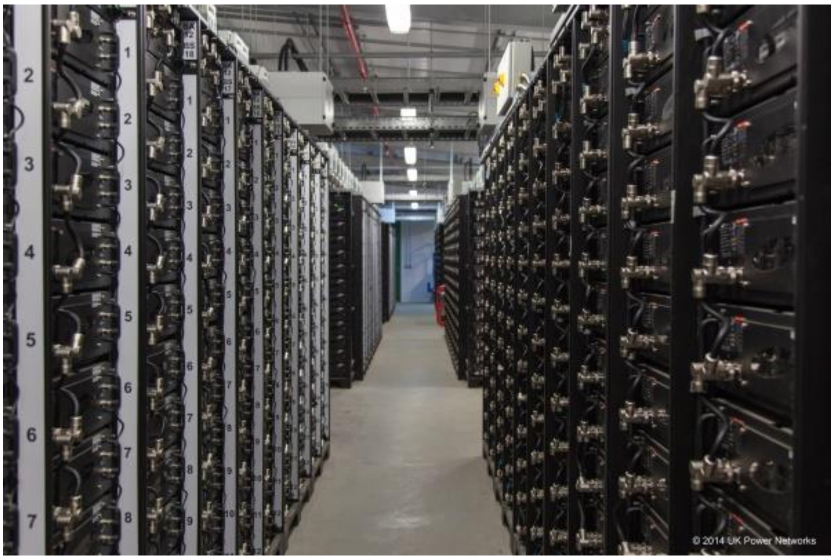
Pumped heat electrical energy storage (PHEES) works by using electricity to power a storage engine connected to two thermal stores containing a substance such as gravel. When prices/demand are low, electricity is used to drive a heat pump which heats one thermal store while cooling the other. To release the energy, the heat pump is reversed to become a heat engine, taking heat from the hot thermal store and delivering it to the cold store, and thereby producing mechanical work. The heat engine drives a generator which produces electricity. Gravel provides a low-cost, abundant means of storing heat. Plant sizes are expected to be in the range of 2 - 5MW.

Flywheels

Flywheels use electricity generated when prices/demand are low to accelerate the flywheel to a high speed, ie energy is stored in mechanical form. Stored energy is then converted by slowing the flywheel down by generating power through a generator. Single flywheel units can typically deliver 100kW of power and store 25kWh, but individual units can be aggregated into a much larger system. Flywheels offer rapid response, and are low maintenance across a long operational life (20 years). However they must be housed in robust containers and the use of precision engineering equipment means they are high cost. In addition, developers may choose to house the flywheels underground so as to reduce noise and visual impact (this solution has been adopted on the County Offaly flywheel project in Ireland).

Developments

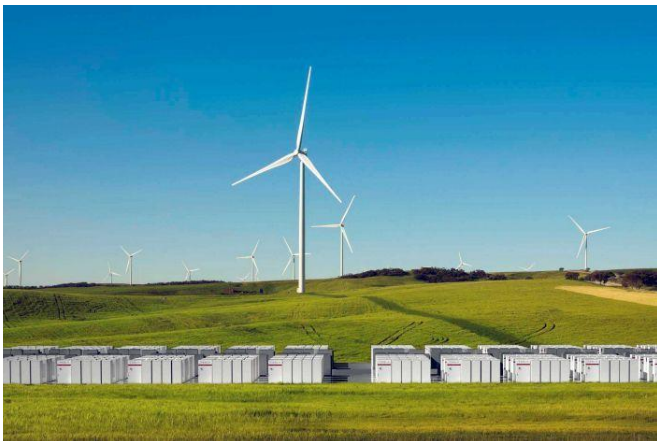
There are several large scale battery systems under development in the UK and in fact there is a grid support system (the Smarter Network Storage facility), the largest electricity storage facility of its type in Europe,



in Leighton Buzzard, Bedfordshire in the UK, the trial will assess the value of energy storage across the system. It is enclosed in two ‘off the ground’ buildings to avoid the risk of disruption from flooding, the 'battery', or to be more precise the collection of multiple Lithium-Ion batteries, itself is a Russian Doll like configuration of 16 individual 3.5KWh cells inside each of the 24 trays that make up the 132 racks. Altogether, it offers 6MW of battery storage capacity, with the in-built availability to scale it up to 8MW. The battery facility will provide a maximum peak power output of 6MW and energy capacity of 12MVAh.

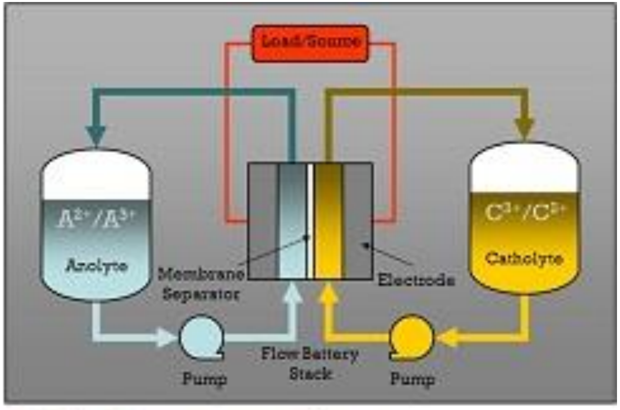
There is a commercial size (two megawatt (MW) lithium titanate battery) storage system at Willenhall substation near Wolverhampton and E.ON and Uniper will use the battery for testing storage technology. It is connected to the grid as part of new research led by the University of Sheffield on the growing area of energy storage. It is an above ground facility as are most commercial sized electric battery systems due to cooling considerations. The above facility is the first to use a lithium titanate battery, supplied by Toshiba. One of the facility’s unique capabilities is how quickly it can respond to demands from National Grid to import or export electricity at short notice – at 4/10ths of a second, it is the fastest of any battery energy storage system in the UK. The lithium titanate battery was chosen because it is fast to charge and discharge, has a long lifetime and is arguably safer than alternatives such as lithium ion. E.ON and Uniper will use the Willenhall battery system to provide ancillary services to the electricity network.

In September 2016, a massive storm ravaged South Australia, disrupting the state's electricity grid and leaving some 1.7 million people without power. Another storm caused more blackouts in December, while a heat wave knocked it out yet again in February this year. In March the state government announced plans to build a large battery storage system to help resolve this issue. Tesla has been awarded the contract for this key component, which will use a scaled up version of the company's commercial Powerpack energy storage system. In fact, it'll be the largest lithium-ion battery storage facility in the world, with a capacity of 100 MW and an output of up to 129 MWh. The Powerpack system will be hooked up to the Hornsdale Wind Farm under construction near Jamestown, storing energy for on-demand delivery to some 30,000 homes.



A Redox flow battery is being built in underground salt caverns at the Jemgum gas storage facility in Germany, (July 2017).

Ewe Gasspeicher GmbH is building this Redox flow battery with enough output to supply a day's worth of power to 75,000 homes.



- **Discharge reaction**
  - $C^{3+} + e^- \longrightarrow C^{2+}$ (reduction)
  - $A^{2+} \longrightarrow A^{3+} + e^-$ (oxidation)
- **Charge reaction**
  - $C^{2+} \longrightarrow C^{3+} + e^-$ (oxidation)
  - $A^{3+} + e^- \longrightarrow A^{2+}$ (reduction)

A Redox flow battery stores electrical energy in liquid electrolytes. Inside the electrochemical cell, two liquids – a positive catholyte and a negative anolyte – are separated by a membrane that allows ions to pass through. When the battery is charging from a power source, electrons are added to the anolyte and released from the catholyte, and that process is reversed while discharging. Charged molecules of each electrolyte are pumped from the cell down into storage tanks, where the energy can be stored for several months.

Ewe Gasspeicher's battery, called brine4power, is based on a system developed by the Friedrich Schiller University in Jena, which uses saltwater electrolytes with recyclable polymers as the active molecules. Those materials, are more environmentally friendly than the heavy metal/sulfuric acid mix that previous Redox flow electrolytes are made of.

The brine4power system will be set up in the Jemgum gas storage facility to make use of two huge underground salt caverns, which are currently used to store natural gas. Each of these cavities has a volume of 100,000 m3 (3.5 million cu ft), giving the battery a capacity of up to 700 MWh and output of up to 120 MW.

The amount of electricity this kind of storage facility contains – consisting of two medium-sized caverns – is sufficient to supply a major city such as Berlin with electricity for an hour. In contrast to other energy storage facilities that convert the electrical current into other energy carriers – for example into compressed air – we are storing the electricity directly with brine4power.

Before the salt caverns are used, the brine4power system will be trialed on-site at Jemgum using large plastic containers on the surface. The company says these will be operational by the end of 2017, with a full underground battery up and running in about six years' time.

More tests and some technical issues must be resolved before the “brine4power” system can be used in the underground caverns but Ralf Riekenberg, head of the brine4power project expects to have an operating cavern battery by the end of 2023.

List of battery storage projects

AES Kilroot Power Storage - Battery Lithium Ion, (10-100 M
In April 2014 the AES Corporation announced plans to build a 100 MW energy storage facility to complement its existing North Ireland power station near Belfast. Contingent on permitting and other approvals, the first 10MW storage facility became operational the second quarter of 2016.

Northern Ireland, Kilroot Northern Powergrid Battery Storage Trial - Battery Lithium Ion, (5.7 Mw(2.85 x 2))
The trial is part of a larger project known as the Customer-Led Network Revolution (CLNR). Six energy - storage devices were installed across a mixture of rural and urban locations in Northern England, to help balance the supply and demand of electricity for thousands of residential and business properties and test the effectiveness of energy storage batteries as part of an overall smart grid solution. Three of the devices have a capacity of 100 kWh, two are 200 kWh and the largest one having a capacity of 5 MWh, making it one of the largest in Europe. Participating organizations include Northern Powergrid, British Gas, EA Technology, Durham and Newcastle universities, with funding by the Office of Gas and Electricity Markets (OFGEM) under its Tier 1 Low Carbon Network Fund. United Kingdom, England, Darlington; plus Northumberland and Maltby, South Yorkshire.

Scotland, Orkney Islands, Kirkwall, Orkney Storage Park Project - Battery, Lithium Ion, (0.5 Mw(2 x 0.25))
In 2013 Mitsubishi Heavy Industries, Ltd. with Scottish Hydro Electric Power Distribution (SHEPD) created a demonstration

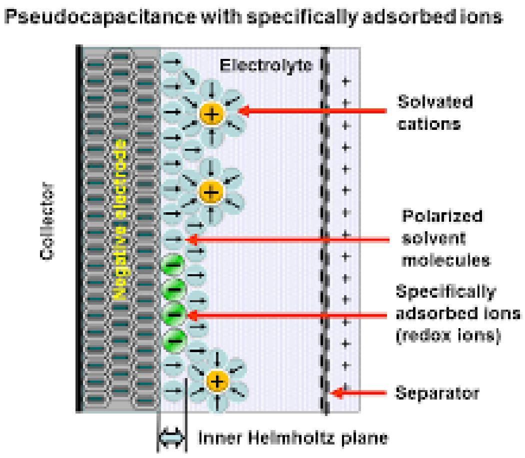
project using the UK's Orkney Islands distribution grid. Funding was provided by the Office of Gas and Electricity Markets (OFGEM) under its Tier 1 Low Carbon Network Fund. The system capacity is 800 kWh nominal, 500 kWh normal usage using two 12 m containers for its batteries and one for its power conditioning system.

England, Leighton Buzzard, BedfordshireSmarter Network Storage - Battery, lithium-ion, (10 Mw (6 x 1.65))
The project is developing control and optimization systems for energy storage. Trials include providing service to distribution network operators and transmission system operators.

South Australia, Hornsdale near Jamestown - Battery, lithium-ion (100MW and 129MwH)
Tesla Powerpack - Power for 30,000 homes in an emergency

Germany, Jemgum gas storage facility in Ewe - Redox liquid flow battery, (700 MWh and output of up to 120 MW)
Gasspeicher GmbH are building a Brine4power system that will provide a day's worth of power for 75,000 homes.

New technology
Basingstoke-based SME ALLOTROPE Power Systems (a spin-out of MAST Carbon) has successfully demonstrated a process to produce a functioning pseudo capacitor (an energy storage device). The pseudo capacitor combines battery levels of energy density with capacitor rates of charging.
Due to difficulties in production, the pseudo capacitor is currently under-exploited, despite its



advantages for many applications. Now, they have been able to use a new design and production method that can translate the energy storing properties of traditional battery materials into a device capable of high discharge power.

This opens the door to a range of novel energy storage devices, which offer an improved energy density over super capacitors, with higher power capability than lithium-ion batteries. It may be that in the future these types of battery can be sensibly installed underground.

Samsung is reputedly redeveloping ‘early technology’ polymer based battery systems for large scale support operations but as yet information is limited.

Conclusion

The batteries discussed above could be used to support the grid in times of strife for short periods. This assumes of course that the infrastructure of the system, including its grid connections had not been damaged. With the exception of the Redox system, none of the above mentioned battery systems are underground: indeed there are only 3 small batteries belonging to Scottish and Southern Power ‘underground’ near Slough and these are relatively small and used only for phase balancing operations. They are only underground because the sub-station itself is underground. That said, it is possible that the MOD have installations of their own but they will be small localized units.

The only large scale underground development is the Redox battery which is a liquid electrolyte system that lends itself to underground storage as it can utilize existing caverns of various types to store the charged electrolyte. Obviously the surrounding strata must be non pervious or suitable for sealing. Significant, is that the system’s capacity is limited only by the storage volume available and as nuclear mining has shown vitrified spherical chambers can be formed of virtually unlimited size in suitable terrain.

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