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ELECTRICITY STORAGE

Storing electricity on a large scale enables power generated when demand is low to be stored for release at peak demand periods. Storage may become more important because renewable energy sources such as wind and solar do not produce constant levels of power. This POSTnote examines existing and proposed methods for large scale electricity storage, examines the technical challenges and discusses the economics of storage relative to other methods of providing electricity reserves.

Background

The Government has set a target of 20% of the UK's electricity to be generated by renewables by 2020[1], while recent EU proposals[2] set the goal even higher, at between 30-40%. As the proportion of energy produced from variable renewable sources such as wind increases, the quantity of backup and reserve services to ensure reliable energy supply will also need to increase.

Renewable energy generation

Unlike current large generating plants, renewable generation units are small, numerous and geographically dispersed, which reduces the chance of a sudden capacity loss through the breakdown of a plant. However, renewable energy generation is variable and intermittent (Box 1) and thus its generation peaks may not coincide with peak demand.

With the UK's present proportion of renewables (~4.6%), variability does not affect the network significantly, but if this percentage increases, the system will require more spare generating capacity to ensure a reliable electricity supply (see Box 2). The capacity needed is determined using statistical models, taking into account the average amount of renewable energy available at peak levels of demand. The government has also recently given approval for new nuclear reactors, which provide an inflexible output of energy due to the complexities of shutting down generation. Balancing supply and demand in a network containing large quantities of both inflexible base-load nuclear power and variable wind power would be extremely challenging. There may be higher reserve costs and some renewable energy may be wasted due to supply exceeding demand on windy days. Storing electricity on a large scale for future use is an option for providing this reserve capacity.

Box 1. Intermittency and electricity networks

All electricity generation is **intermittent** to an extent because of interruptions from maintenance or breakdown. Most forms of renewable generation are also **variable**, as the amount of electricity they generate depends on outside factors, such as the wind speed for wind generation or the amount of sunlight for solar panels. Power station output is measured in **megawatts**, MW, with one megawatt being enough to power 10 thousand 100W lightbulbs. A kilowatt, or kW, is one thousandth of a megawatt.

The **transmission** network, or grid, transmits electricity across the UK from generating stations on large high-voltage overhead lines and underground cables. The **distribution** networks transmit electricity at lower voltages on a regional scale, taking energy from the Grid to consumers.

Balancing supply and demand on the grid

The UK's energy network has to maintain a very fine balance between demand and supply to ensure grid stability (see POSTnote 280). Therefore, the network requires a certain amount of reserve capacity to ensure a reliable electricity supply. The National Grid is responsible for ensuring the security and quality of the electricity supply in the UK. Demand can vary significantly depending on weather conditions, daylight hours and even the timing of popular television programmes. Supply can also change quickly, for instance if a large power station suffers a sudden breakdown.

The National Grid is prohibited from operating generating plants. It therefore contracts out reserve energy generation. Large **coal** and **combined-cycle gas turbine** plants (CCGTs), power plants that are paid to run below full capacity, provide reserve for smaller, more frequent fluctuations. Running power plants below full capacity makes them more inefficient, burning more fuel to generate each unit of electricity.

For larger, less frequent imbalances, **open-cycle gas turbines** (OCGTs) are also used, as are diesel generators. These are often referred to as *standing* reserve, as they are run only when necessary. OCGTs are smaller and have greater running costs than CCGTs. The UK also has several **pumped hydroelectricity** storage plants (Box 3) capable of providing reserve power. Reserve capacity is allocated by calculating the point at which the efficiency losses of running partially loaded CCGTs are greater then the costs of running OCGTs.

Box 2. Case Studies: Denmark and Ireland

Denmark is the largest wind energy producer per capita in the world, generating the equivalent of 24% of its national supply. It regularly produces more wind energy than its electricity network can consume. The Danish grids are well interconnected, allowing it to sell excess power at low costs to Sweden, Norway and Germany.

Recently, the Danish Parliament passed a law allowing electric heating of water in the country's many combined heat and power (CHP) stations. Therefore, when excess wind energy is available, it can be used instead of natural gas for district heating, reducing CO_2 emissions. This can be seen as 'storing' the electricity in the form of hot water.

Ireland has a goal to reach 33% of wind penetration by 2020. Like the UK, it has an island network with limited interconnection capacity. The Irish government's 2007 All-Island Grid Study[1] concluded that 42% of Ireland's electricity could be met by wind without drastic changes to the electricity grid. However this would at times require restricting wind generation due to excess supply.

Electricity storage technologies

Electricity storage has a large variety of potential uses in a modern electricity network. It can be thought of as analogous to a warehouse or a water tank – a place where excess can be stored to make a network more efficient. The services a storage unit provides depend on where it is *placed* in the network, the amount of *energy* it can store and the rate at which it can deliver that energy – its *power* rating.

Flywheels and supercapacitors

Low-energy, high-power storage systems such as **flywheels** and **supercapacitors** are used extensively as uninterruptible power supplies and for regenerative braking in cars and trains. Due to their relatively low energy storage potential, resulting from materials limitations, these technologies are not thought to have many applications at the transmission level, instead being used by large commercial and industrial energy consumers to maintain the reliability of power supplies.

Geological storage technologies

Compressed air energy storage (**CAES**) involves storing air at high pressure, often in a large underground space, before using it to power a turbine. It, and **pumped hydro** (see Box 3) are larger scale, high-energy, high-power systems, capable of providing significant reserve services. They suffer, however, from significant geological restrictions, severely limiting the locations where they can be built. Neither technology is likely to be developed at a large scale in the near to medium future in the UK, although smaller-scale versions have promising prospects for distributed local storage for microgeneration.

Battery storage technologies

There are many **battery** storage technologies available, including lead-acid, lithium-ion, sodium-sulphur and sodium nickel-chloride designs. Sodium-sulphur batteries have been extensively tested in Japan, and a 34MW system is being installed at a wind farm there.

An alternative technology to conventional batteries is **Flow-cell** battery storage (see Box 4). A large battery installation would usually be in the 100kW-10MW range, and would be used to help balance the electricity network as well as engaging in energy arbitrage, where energy is bought and stored at cheap off-peak rates and sold back to the grid at expensive peak times.

Box 3. Pumped hydroelectricity storage

Pumped hydroelectricity storage is the oldest form of large-scale electricity storage. Two reservoirs are separated by a large height difference. During periods of low demand and cheap electricity, water is pumped from the lower to the higher reservoir. At peak demand periods, water is then allowed to flow from the upper reservoir back to the lower through large turbines which generate electricity. Approximately 75-80% of electricity used can be recovered.

The UK has roughly 2,800MW of pumped storage capacity, the largest of which is the **Dinorwig** plant in Wales, capable of providing 1728MW (approximately 1.5% of the UK's peak winter energy needs) for 5 hours when full. Pumped storage is used for many applications, including providing peak demand levelling, fast reserve, energy arbitrage and emergency grid restart services.

Pumped hydro has found it difficult to compete for contracts in the current liberalised energy market against smaller, less expensive OCGTs. In 2007, two of Dinorwig's six turbines were mothballed until further notice.

Siting of large-scale storage

Energy stores, with the exception of extremely large projects such as pumped hydro, should be easy to site. They are fairly small and produce no operational emissions. Most modern systems are modular, so they could be expanded readily to suit the demands of the network. Storage technologies are generally relatively quick to build and should not require long lead times. However, storage generally has high initial costs, leading to long (over 10 years) payback times. The length of time required to recover investment has led to little interest from UK energy companies.

Generation level

Storage units can be placed next to wind farms by generating companies to produce a consistent flow of power from the farm. The storage unit absorbs excess power during periods of strong wind and uses it to supplement the power flow during periods of calm. This increases the generation reliability, allowing it to be sold for a higher price. This, however, must be offset against the cost of the store, which can often be as much as or more than another wind turbine. This very high cost and the long pay-back times have put off large-scale investment by generating companies.

Box 4 Flow-cell electricity storage

Flow cell battery storage uses two salt solutions to store electricity. These can be charged and discharged by being pumped through a reaction cell, where a chemical reaction takes place.

Flow cells have several advantages:

- energy and power are *separated* in the system – energy relies on the amount of solution available, whereas power depends on the size and number of reaction cells. This makes flow-cells modular and easily expandable;
- flow cells can also be fully *charged and discharged* without problems, unlike conventional batteries.

However, they have disadvantages:

- they have lower *energy densities* then conventional batteries, requiring more space for the same storage capacity;
- they also tend to have lower *efficiencies* then conventional batteries, typically around 70%.

The vanadium-vanadium flow-cell battery (VFB) is the technology currently under heaviest commercial development. A demonstration plant is operational at a wind farm in Japan (4MW) and one is proposed at a wind farm in Ireland. (2MW) . A Sustainable Energy Ireland report[3] on this flow-cell concluded the minimum pay-back time was 10.6 years at 2006 energy prices.

Transmission level

Storage can also be used to provide services to the transmission network. These include the contracting of reserves to the National Grid, as well as energy arbitrage and providing the initial start-up energy for power stations in case of a large-scale grid shutdown. Pumped-hydro plants such as Dinorwig in Wales and Foyers in Scotland perform these services on a large scale.

Distribution level

Storage can effectively expand the capacity of distribution networks by providing a smoothing service. It does this by providing any power required beyond the peak capacity of the network by using energy stored at off-peak times. A 250kW VFB flow-cell was installed in a remote community in Utah, USA to supply excess power at peak usage times. The capital cost of the flow-cell was a quarter of the cost to upgrade the electricity link.

Microgeneration

Storage can also be used close to consumers, to ensure the quality and reliability of delivered power is maintained. Domestic microgeneration can feed back into the grid and in doing so can cause voltage and current fluctuations in the local power network. An energy store can help to compensate for the imbalances caused by distributed generation, allowing distribution networks to integrate larger quantities of microgeneration. An EDF energy pilot scheme in the UK aims to build and test a small energy store to examine its potential as a part of the distribution network.

Government interest

Innovations in electricity networks to incorporate variable renewable sources were called for in the *2007 Energy White Paper*. Parliamentary questions have also been tabled on electricity storage and integration of intermittent sources[4].

The Department for Business, Enterprise and Regulatory Reform, DBERR, has commissioned several reports on storage in the UK, including its economic value[5] and ability to enhance security of supply[6] and on the status and viability of storage technologies[7]. DBERR part-sponsored the "Regenesys"[8] scheme with IVTL in 2001 to build a pilot flow-cell battery as a 12MW storage system at Little Barford power station. The project encountered severe technical difficulties and in 2003, after ITVL was acquired by RWE energy, it withdrew funding. The project was subsequently discontinued.

Storage advocates have called for another demonstration plant to be built to test for the optimum methods of running a system utilities store. Some academics, however, say there is little point in building a demonstration plant, as a far cheaper economic study would provide the same data.

Economic considerations

Large storage units have high capital costs and will therefore have a pay-back time of many years. To add to this, conventional battery stores have a limited number of charge cycles before they must be replaced, which adds significantly to maintenance costs. Storage also has an efficiency of between 50-80%, depending on the technology.

A storage facility would have to compete against open-cycle gas turbines (OCGTs) for contracts to provide standing reserve. OCGTs have lower capital costs and running costs dictated by the price of natural gas. They typically cost around £300/kilowatt, though this cost is increasing rapidly with the price of gas.

A 2004 DBERR report[5] placed storage as being more valuable to the network operator than OCGT reserve, due to the reductions in fuel used and carbon dioxide emitted. This extra value was between £60-£120/kilowatt. However, no large-scale storage technology has come close to meeting this cost. The break-even point for the Regenesys project (providing arbitrage and reserve services) was £1200-1500/kilowatt, but the project was unable to meet this target.

Demand-side management

Storage will in the future face competition from demand-side management (DSM) technologies (Box 5), which have no efficiency losses and smaller capital costs. DSM is seen by market observers as an important development for future energy networks, though there would have to be significant rollouts of smart metering (see POSTnote 301) and suitable appliances. Considerable restructuring of electricity tariffs would also be needed for DSM to be viable on a large domestic scale.

Box 5 Demand-side management

Demand-side management (DSM) is a series of technologies which aim to match the demand of an electricity system to the available supply. DSM could be integrated with smart metering and communication to monitor available energy supply and pricing. Appliances would turn on and off dynamically to ensure demand matched available energy supply. As demand is controlled, there are no efficiency losses, unlike storage. As DSM can be rolled out gradually, the capital costs are also far more incremental than storage.

Appliances suitable for DSM are water heaters and fridges, which are not affected by a short (up to 20 minutes) electricity outage. Greater demand control can be achieved by scheduling appliances to run at periods of lowest demand. RLtec Ltd estimates the amount of energy 'stored' by scheduling the UK's 10 million dishwashers to run at lowest demand times as enough to provide most of the UK's balancing needs.

DSM has disadvantages, however. While industrial and commercial DSM, dealing with large sites with predicable demand, is not particularly difficult to implement, domestic DSM would be slow to roll out and will require implantation in new domestic appliances. The lifestyle changes needed for efficient DSM may also be unpopular with domestic consumers, while innovation in the structure of the energy market would be required to ensure DSM benefits energy suppliers as well as transmission operators and distributors.

Operation in the UK's energy market

Another issue is the difficulty of operating electrical energy storage to its maximum economic potential. To do this, an energy store must perform many different tasks including providing standing reserve capacity, load-levelling for transmission and distribution lines, grid-restart facilities and energy arbitrage.

Some storage consultants have expressed dissatisfaction with the UK's current liberalised electricity market because each of these services is contracted separately, so that the benefits cannot be grouped for economic efficiency. They propose a regulatory change that allows transmission companies to own and operate storage. This would reduce project risks and encourage the adoption of more storage technologies, bringing advantages to generators, network operators and consumers of electricity.

The long payback times in a market which has the potential to change quickly and significantly over coming years has left investors wary, with many large energy companies either not investing at all or funding only extremely limited pilot schemes and studies.

Storage in the future

Reserve costs increase with greater proportions of variable generation, due to the need to have more reserve provision available. Reports have concluded[9] that reserve costs on the current grid at a 20% level of wind power would add only between 2-5% to domestic bills. As of yet, there have been few major studies examining the effects of greater contributions from wind generation, but academics expect reserve costs to continue to rise with greater quantities of wind.

Most observers agree that the economic viability of storage may increase in the future as fossil-fuel based reserve becomes more uncompetitive, both through rising fuel prices and more expensive carbon trading credits. Capital costs of storage technologies may also decrease as more mass-production capability comes on line. There would however need to be a very large increase in the price of fossil fuels, particularly gas, before storage became economic compared with conventional reserves.

The value of storage over OCGTs also increases with large quantities of both wind and nuclear power. Storage can absorb excess wind energy, which would be otherwise wasted using conventional reserves. There would also be larger variations in energy prices between peak and off-peak times, making energy arbitrage more profitable.

Overview

- Electrical energy storage has a variety of potential uses in a modern electricity grid, including providing reserve power and improving reliability of networks.
- There are significant economic issues in deploying storage, stemming from the high capital costs and complexity of operating in liberalised energy markets.
- As the proportion of power generated by wind and nuclear increases, storage may become more economically viable.
- The major competitors to storage are conventional fossil-fuel reserves and demand-side management technologies.

Endnotes

1 *Meeting the Energy Challenge: A White Paper on Energy*,DBERR, 2007

2 *EU Renewable Energy and Climate Change Package*

3 *VRB ESS Energy Storage and the Development of Dispatchable Wind Turbine Output* SEI, 2007.

[4] HC Deb, 24 November 2005, col 2207W

[5] *The Future Value of Electrical Energy Storage in the UK with Generator Intermittency*, DBERR, 2004.

[6] *Enhancing Security of the UK's Electricity System with Energy Storage*, DBERR, 2006.

[7] *Status of Electrical Energy Storage Systems*, DBERR, 2004

[8] *Regenesys Project Summary*, DBERR, 2004.

[9] *The Costs of Intermittency*, UK Energy Research Centre, 2006

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