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Energy Storage and Demand Management

Farm Advisory Service

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Summary

- **Opportunities exist for small scale "behind the meter" storage for owners of renewable assets and on-site demands but careful financial analysis and system design is needed.**
- **The demand for grid balancing services will increase as smart grids are developed and system operators procure these services at a local level. Storage installations will play a role in this market.**
- **Grid balancing can also be facilitated by controlling demand (i.e. turning down large loads during periods of peak demand).**
- **Storage technologies that can be appropriately deployed at a farm scale include; batteries, heat storage and hydrogen production.**
- **A range of revenue streams can be accessed by storage operators including reduced energy import costs, the ability to trade electricity at more attractive price points and receipt of payments for providing grid balancing services.**

Introduction

A wide range of technologies are now being employed in the generation of electricity and many of these, including wind and solar generators, have a very variable production pattern. In addition, generators are now spread far and wide across the electricity networks rather than the old model of large scale centralised power stations. Although this diversity brings many advantages, it also brings challenges in matching supply and demand. The next step in the energy revolution is to develop a "smart" network infrastructure that can take full advantage of this diversity and maximise the benefits to consumers as well as energy companies. Storage technologies have also developed apace and will have a huge part to play along with demand management as this smart network develops. These solutions can be employed at a very small scale "behind the meter" for the benefit of farms and other consumers, but can also be employed at a larger scale to support the wider electricity market.

Why install energy storage equipment?

Energy storage systems provide a wide range of services each of which will fall into one of three groups;

A. **Price & time shift** – Energy may be stored until it can be used or sold at a time of peak demand when the price is higher. This could include energy generated by renewable resources or even energy purchased from the grid when prices are low.

B. **Response** – the ability to respond quickly when energy is required. This can be measured in anything from milliseconds to minutes. Fast response is a service required to maintain the frequency of an electricity supply within designated limits. There is a greater requirement for this service where intermittent generators such as wind and solar are dropping in and out of production.

The European Agricultural Fund for Rural Development
Europe investing in rural areas

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C. Reserve – straight forward storage of energy in reserve for use at a later time when it is required. This could include reserve at a local level as a back up supply in case of power cuts or at a larger scale to provide energy to the grid to cover periods of high demand or low generation. Unlike "response" requirements for reserve energy are normally scheduled in advance and output needs to be sustained for a longer period of time.

Farm based storage

Farm businesses may consider energy storage technology for a number of different reasons which will fall under one or more of these three categories;

To serve an on-site demand (A & C)

Storage may allow energy users to store energy produced by their own renewable energy assets for use at times when generation is limited. It can also help consumers to reduce bills by allowing them to purchase energy at a low tariff at a time when there is a low demand on the distribution network and storing it to meet an internal demand at other times. In some cases storage may also be used to provide short term continuity of supply in case of a power cut or allow a high demand to be served for a short period, without the need to upgrade an incoming supply.

To serve connected generation (A)

As well as retaining home generated electricity for on-site use, storage can also allow those with renewable energy assets achieve a better payment rate for exported energy, by storing it for export during periods of peak demand.

To obtain an income by providing a storage service for electricity system or network operators (B & C)

The "national grid" is the high voltage (275 kV and upwards) electricity transmission system that moves energy around the UK from large generating stations to local grid supply sub-stations. *National Grid Electricity Transmission Plc* is the system operator (SO) charged with managing the security of this **system** across the UK. The SO procures "ancillary services" to enable them to ensure that the lights stay on across the wide range of supply and demand patterns encountered from day to day. Increasingly, some of these ancillary services can be supplied by storage technology operators.

The UK Electrical Power Transmission System

Traditionally, electricity has mostly been generated in large scale power stations and the network was designed to transmit power from these centralised generators and distribute it to consumers around the country. The network is therefore laid out like branches of a tree; with large conductors leaving the power stations and branches reducing in size as they approach individual consumers. With the increasing amount of dispersed renewable generators (distributed generation) connected to the network in remote locations, the demands on this network have changed and upgrades to the network now need to address this issue. In addition, patterns of energy use have changed and will continue to do so with the increasing deployment of electric vehicles.

Separate network operators manage the physical electricity network infrastructure. The actual physical **transmission** network infrastructure in Scotland is developed, operated and maintained by one of two transmission network operators;

- SP Transmission in the south and,
- Scottish & Southern Electricity Networks
  - Transmission in the north.

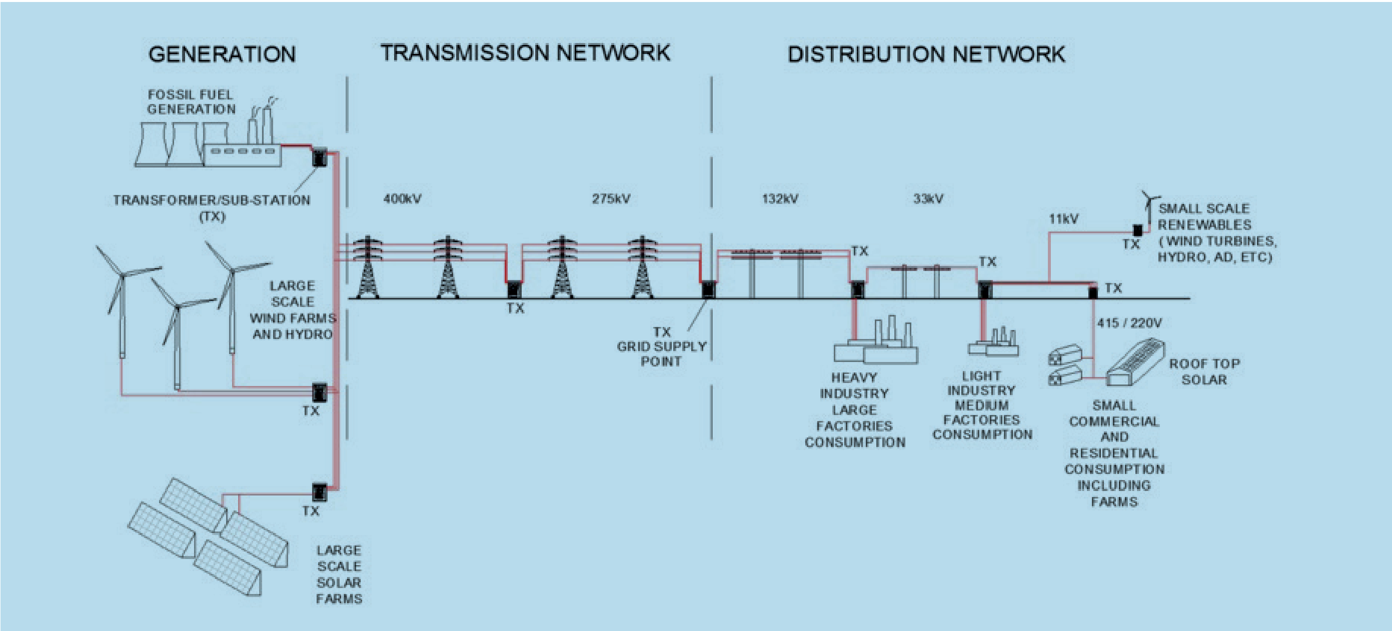

Figure 1. Diagram of UK Electricity Network

Distribution networks are the lower voltage (132 kV and below) parts of the network between the transmission network sub-stations (or grid supply points) and the end customers. These networks in Scotland are developed, operated and maintained by one of two licensed distribution network operators;

- SP Energy Networks in the south and;
- Scottish & Southern Electricity Networks in the north.

Ancillary Services procured by the system operator (SO)

With generators and consumers continually trading electricity on and off of the network the SO (National Grid) uses a range of services to keep the system continually in balance. Owners of storage facilities can obtain revenue by having energy on standby with the ability to supply it on demand or alternatively having a load in reserve that can be switched on to absorb excess energy. The SO has a range of different requirements classified by the speed at which a provider can respond to a request and the length of time the output (or demand) can be maintained. The range of balancing services currently purchased by the SO include the following; Enhanced Frequency Response, Firm Frequency Response, Fast Reserve, Short Term Operating Reserve and Black Start. Contracts for supply of these services are put out to tender on a regular basis and currently contracts are awarded for short periods only. They also operate the "Capacity Market" which is one of the main building blocks of the UK Government's Electricity Market Reform programme, within which suppliers can bid to guarantee to supply electricity during a future time period in times of system stress. Capacity payments are made over and above sales of energy for maintaining the ability to supply during the relevant periods. All of these ancillary services can provide income streams for owners of energy storage facilities. Work is currently on-going to modernise these services and the way in which they are procured by National Grid, which aims to make this market more accessible to a wider range of technologies and scale of installations. Whereas in the past many of these services have been supplied mainly by large scale centralised power stations with the ability to turn up or turn down at short notice, they are increasingly being fulfilled by small scale standby and renewable generators and storage facilities.

Demand management

Peaks in energy requirement can also be met by turning down larger customer's demands for short periods of time. Consumers offering to provide this "turn down" service can receive payment for making this facility available. With easier remote control of this facility over the internet it is also possible for many small loads to be controlled by aggregators and turned up or down in unison providing one way of smaller players entering this market. The current process to simplify this market will make it easier for small generators, storage operators and consumers with controllable loads to tender for these services in a more transparent fashion.

Distribution "System" Operators

Further changes to the electricity distribution system will see the distribution network operators (DNOs) become distribution "system" operators (DSOs) who will then also be able to contract these types of balancing services at a more local level, providing further opportunity for smaller players to enter this market. One mechanism that is likely to be introduced is the "time of use" tariff which will simplify the process by which storage system operators can buy or sell electricity at a time when they can obtain the best tariffs.

Sizing a storage installation

Energy storage systems can be described by a number of technical characteristics;

- **Power rating (MW)** – The peak power a storage device can deliver.
- **Energy capacity (MWh)** – How much energy a storage device can store and deliver over time.
- **Response time (milliseconds to minutes)** – How quickly a devise can react and start importing or exporting energy after it receives a request.
- **Cycle efficiency (%)** – The amount of power that you get back from a storage device compared with the amount you put in.
- **Life (years or charge-discharge cycles)** – How long a device will remain effective in service.

Storage Technologies

There are many established energy storage technologies already deployed across Scotland and many more new technologies being developed. The more commonly known include; pumped storage hydro, thermal storage, battery storage, hydrogen, flywheel storage, liquid air, and compressed air storage. This technical note deals with the technologies that have the most potential to be deployed at a farm scale and in particular battery storage, thermal storage and hydrogen.

Battery storage

Batteries come in many shapes and sizes, all of which store electricity in the form of chemical energy which they can later turn back into electricity. Types of battery include; lead-acid, sodium-sulphur, lithium-ion, nickel-based, metal-air and flow batteries. Lithium-ion and lead acid are currently the most common types being offered for use at a farm scale.

Lithium-Ion batteries;
Developed for consumer products such as phones and laptop computers; now used in electric vehicles and as small scale energy storage systems often linked to solar rooftop arrays and also used in multi-megawatt containerised storage

Lead-acid batteries;
Although a relatively old technology, lead-acid batteries still offer a cost effective technology for grid back-up due to their lower cost. Life expectancy is lower than lithium-ion and depth of discharge (DOD) is poorer, meaning that they will require re-charging before they have discharged to a low level.

Flow batteries
These work on a different principle than conventional batteries in that the energy is stored in the electrolyte and therefore, the bigger the volume of electrolyte the more energy that can be stored. These offer greater flexibility for grid scale storage as the power rating can be tailored to the demand and the amount of energy that can be stored is defined by the size of the electrolyte tank.

The delivered cost of energy from a battery storage system
For small scale installations the benefit of a battery storage system will often purely rely on savings in overall energy costs at the site. To inform a decision on whether battery storage would make a good financial investment at your site an assessment of the cost can be made as follows;

Example:

A battery storage system with a useable capacity of 14 kWh is to be installed at a site with a regular night time load that will consume all of the stored energy daily. The battery will be charged through the day from on-site renewable resources. The equipment is warranted for 6000 cycles and costs £5,900.

$$p/kWh = \frac{5{,}900 \times 100}{6000 \times 14}$$

= 7.02 p/kWh over the life of the storage system

(Excludes any lost revenue from exporting energy directly to grid as generated)

Cost of energy delivered from the battery system;

$$p/kWh = \frac{\textit{Installation price (£)x 100)}}{\textit{total kWh delivered during life of system (kWh)}}$$

Manufacturers will often provide a warranty up to a maximum number of charge/discharge cycles and will also provide a specification for the useable storage capacity. Where a system is designed to completely charge and discharge every cycle, then a crude estimate of the total energy delivered during the system life can be made by multiplying the useable storage capacity by the number of warranted cycles.

When used to "time-shift" renewable energy for on-site consumption and if the renewable generator has the facility to export energy to the grid through an export meter then there would be lost revenue from this source. At the time of writing, this could be around 5.5 p/kWh making the true cost of the energy delivered from the battery in the example 7.02 + 5.5 = 12.52 p/kWh. Where FIT export payments are made on a "deemed" basis for small systems, there will be no loss of income from this source.

Based on these figures, an installation of this type will be financially viable in a limited number of situations and careful analysis of usage patterns is recommended before committing to an investment. However, as the cost of batteries reduce and the cost of electricity increases this type of system will become viable at many more sites.

Thermal storage

Where a site has an ongoing heat demand the option exists to store energy produced from renewables or purchased at low "off-peak" rates until it is required. The simplest way to do this is to heat water in a highly insulated thermal store and then draw the heat off as required. Careful system design is necessary to ensure that heat is available when required and also that the capacity to absorb energy during periods of high renewable generation or low import rates also exists. As an alternative to water, heat batteries employing phase changing materials will provide a more efficient heat storage medium in a smaller space. When assessing the financial viability of thermal storage, it is important to consider the cost of the energy source being substituted. If renewable electricity from a metered export is diverted to offset heat that would normally come from an oil boiler or a wood fuel boiler for example, then the saving on these fuels may be similar to the lost revenue from electricity export. If however, renewable electricity is used to offset imported electricity the financial benefit would be the difference between the import and export rates available. Where FIT export payments for renewable electricity are made on a "deemed" basis for small systems, there will be no loss of income from this source and the business will benefit by the total value of every unit of energy offset.

Hydrogen

Using electricity, water (H_2O) can be split into hydrogen and oxygen. Hydrogen can be stored and then used in a fuel cell to produce electricity or as a combustion fuel. Hydrogen can therefore be used as an energy storage medium. The round trip efficiency of electricity to hydrogen and back to electricity can be as low as 30% to 40% but could increase to 50% as technologies develop. Despite the low efficiency there is increasing interest in the production of hydrogen from renewable energy as a storage medium due to greater potential storage capacity than some other technologies. Direct use of "green" hydrogen as a heating fuel or a transport fuel is another area of development. A proportion of hydrogen can be blended with natural gas in the domestic gas network and this is being trialled in a number of countries. Hydrogen powered vehicles are commercially available and a national network of hydrogen re-fuelling stations is planned. Pros and cons of hydrogen as a vehicle fuel include;

- **Pros**
  - Can be produced locally
  - Can be stored
  - Can be transported to an extent
  - No greenhouse gas emissions from vehicle, only water vapour

- **Cons**
  - Very low energy density and therefore high pressure storage is required if a useable vehicle range is to be achieved
  - Flammable in air
  - Easily ignited
  - Hydrogen/air mixtures can explode
  - May burn with almost invisible flame
  - Distribution network not yet in place

Until a wide hydrogen re-fuelling network exists there are a limited number of situations where hydrogen vehicles offer a viable option. These include fleet vehicles with their own re-fuelling facilities where the vehicles operate within a small radius and return to their base regularly where refuelling can take place. Hydrogen fuel has been trialled on inner city bus fleets and on local authority refuse collection and other service vehicles.

Revenue from large scale storage installations

A viable income from large scale storage projects is more likely to be achieved by "stacking" a number of different revenue streams. For example, by contracting to provide a range of separate "reserve" services to the SO and also providing the opportunity to "price & time shift" to renewable generators such as wind farms. Scotland is a net exporter of electricity and suffers from a higher than average incidence of grid constraint and high transmission charges. Storage can be used in some situations to alleviate these issues. Currently access to these different revenue streams is complicated, contract lengths can be short and timescales for separate products are not aligned, making it difficult to raise finance for stand alone storage projects. One option for landowners wishing to obtain an income from large scale energy storage is simply to lease land to specialist storage operators who will often have links to large renewable generators or electricity supply companies. On-going market reforms aim to open up opportunities for smaller players.

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