

ARUP

Five minute guide

Electricity Storage Technologies

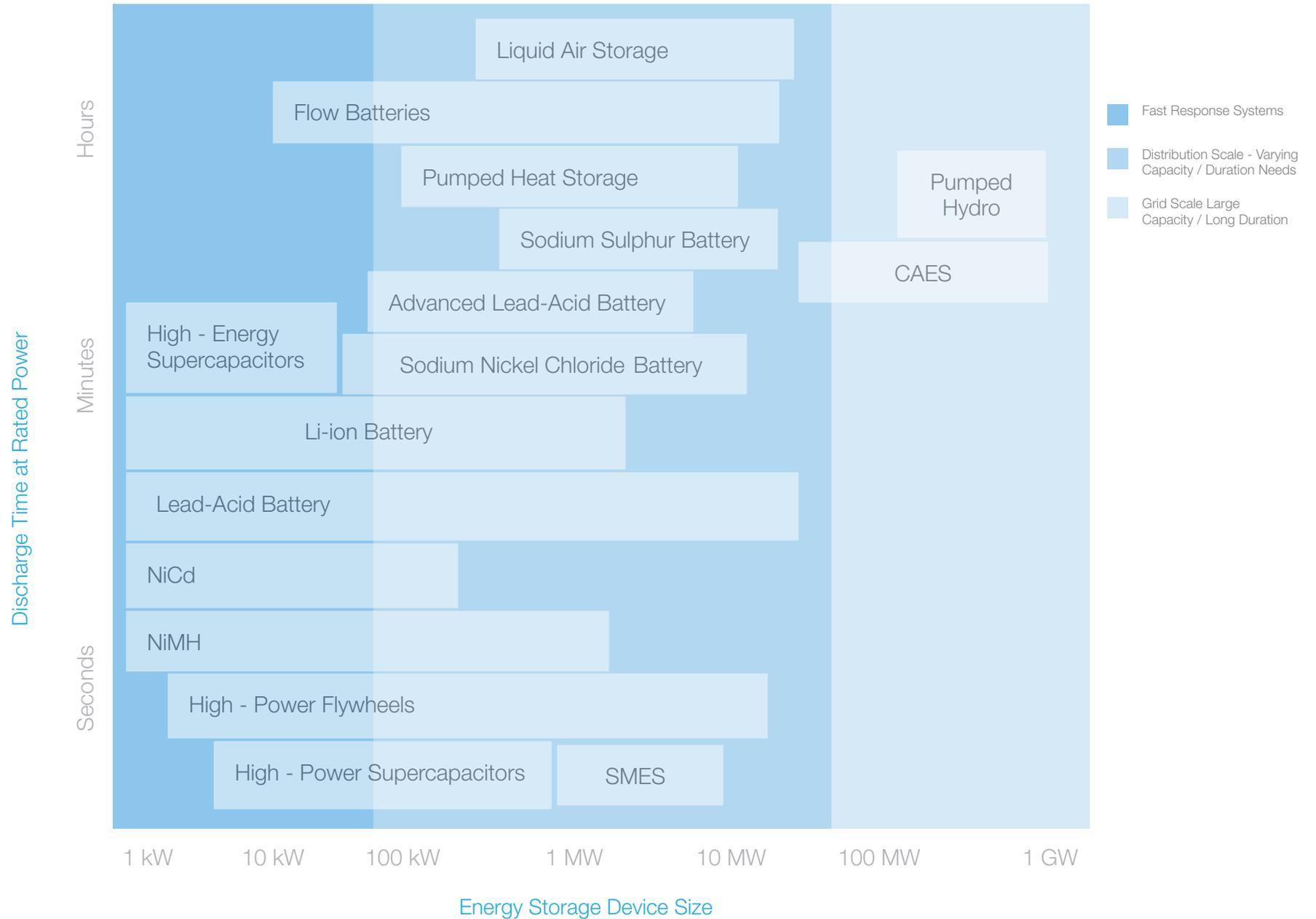
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The need for storage

Storage need	Revenue stream	Required discharge time frame	Required storage capacity
The ability to match generation and demand. Shift generated energy from off peak times to when it is needed. Grid level and small scale domestic applications.	Price arbitrage, reduction in demand charges	Minutes - Hours	kW - MW
Peaking plants are needed in order to meet changes in supply and demand conditions. Storage could provide this capacity in certain circumstances and reduce the need for fossil fuel peaking plants.	Electric supply capacity – power capacity contract and price arbitrage	Hours	MW
Increase the efficiency of thermal generation by ensuring a constant output. Storage can provide these load following services.	Load following – power capacity contract	Minutes - Hours	MW
Storage can be used to reconcile momentary differences between supply and demand. Storage can both adsorb and provide energy providing a twofold service.	Balancing services – power capacity contract	Seconds - Minutes	MW
Storage can provide reserve capacity that can be called upon in the event of the usual electricity supply resources becoming unexpectedly unavailable.	Electric supply reserve	Hours	MW
To maintain voltage and frequency at the required levels following a large disturbance requires a fast response. Storage can provide this service.	Regulation response and voltage support – Avoided penalties from system operator	Milliseconds - Seconds	kW - MW
Energy storage used for transmission support improves T&D system performance by compensating for electrical anomalies almost instantly.	Transmission network support – Avoided penalties from system operator	Milliseconds - Seconds	kW - MW
Transmission systems are becoming congested during periods of peak and off peak demand. Storage can be used to mitigate this issue instead of investment in new transmission assets.	Asset upgrade deferral – Avoided cost of infrastructure investments	Hours	kW - MW
Storage to provide energy in the event of a system failure until the system is restored or alternative energy sources are available.	Electric service reliability – Reducing production / operating losses	Hours	kW - MW

Application and technology overview



Sodium Sulphur (NaS) Batteries

Technology Description

A sodium sulphur battery is a molten state battery constructed from sodium (Na) and sulphur (S). The battery casing is the positive electrode while the molten core is the negative electrode. The battery operates at high temperatures of between 300-350°C, while lower temperature versions are under development. In charging, the sodium ions are transported through the ion selective conductor to the anode reservoir. Discharge is the reverse of this process. Because sodium ions move easily across the ion selective conductor, but electrons cannot, there is no self-discharge. When not in use the batteries are typically left under charge so that they will remain molten and be ready for use when needed. If shut down and allowed to solidify, a reheating process is initiated before the batteries can be used again.

Advantages

- High energy density
- Long life cycle
- Quick response
- Efficient in charge-discharge cycles
- Able to tolerate a high number of charge/discharge cycles

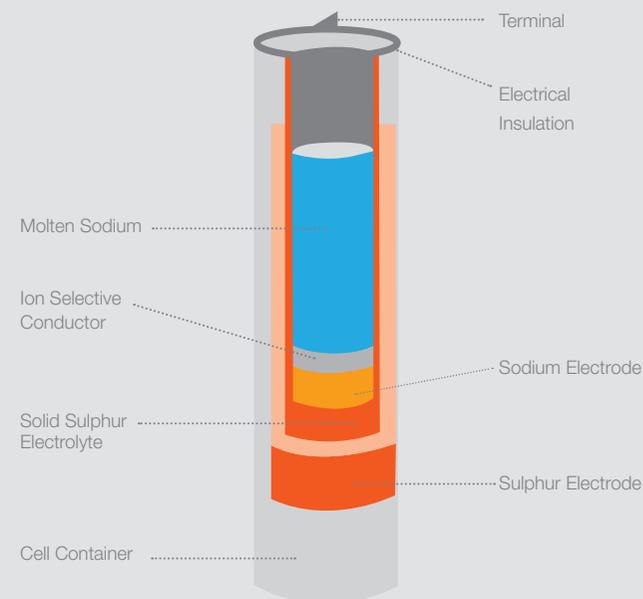
Disadvantages

- Heating may be required
- Potential safety issues with the molten sodium
- Fire issue at a Japan installation

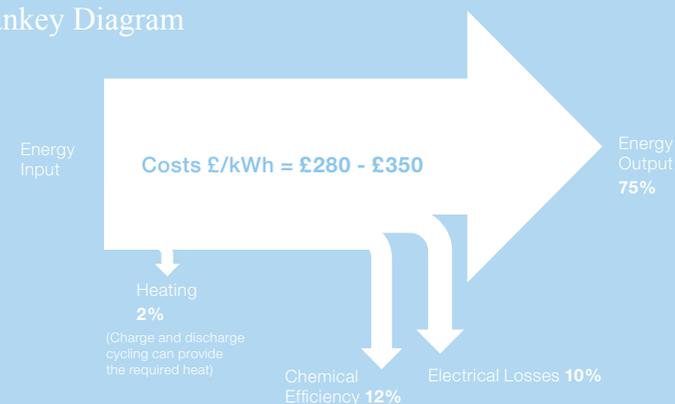
Applications

There are over 300 grid applications of NaS batteries worldwide, with the majority of these located in Japan. NaS batteries can be used for many grid applications such as: Power quality applications, grid stabilisation and the integration of renewable energy sources. 34MW of NaS batteries have been integrated to the Futamata wind farm in Japan. The batteries store the energy generated at night and combine this with the wind farm output during the times of greater demand in the day.

Cross section of a NaS battery



Sankey Diagram



Flow Batteries

Technology Description

Flow batteries are a rechargeable battery using two liquid electrolytes, one positively charged and one negative as the energy carriers. The electrolytes are separated using an ion-selective membrane, which under charging and discharging conditions allows selected ions to pass and complete chemical reactions. The electrolyte is stored in separate tanks and is pumped into the battery when required. The storage capacity of flow batteries can be increased by simply utilising larger storage tanks for the electrolyte. Several chemistries are possible for the battery.

Advantages

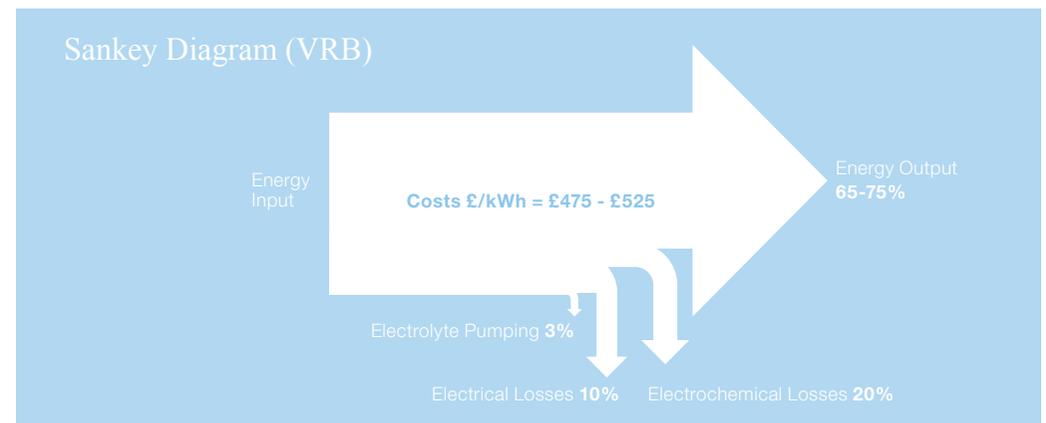
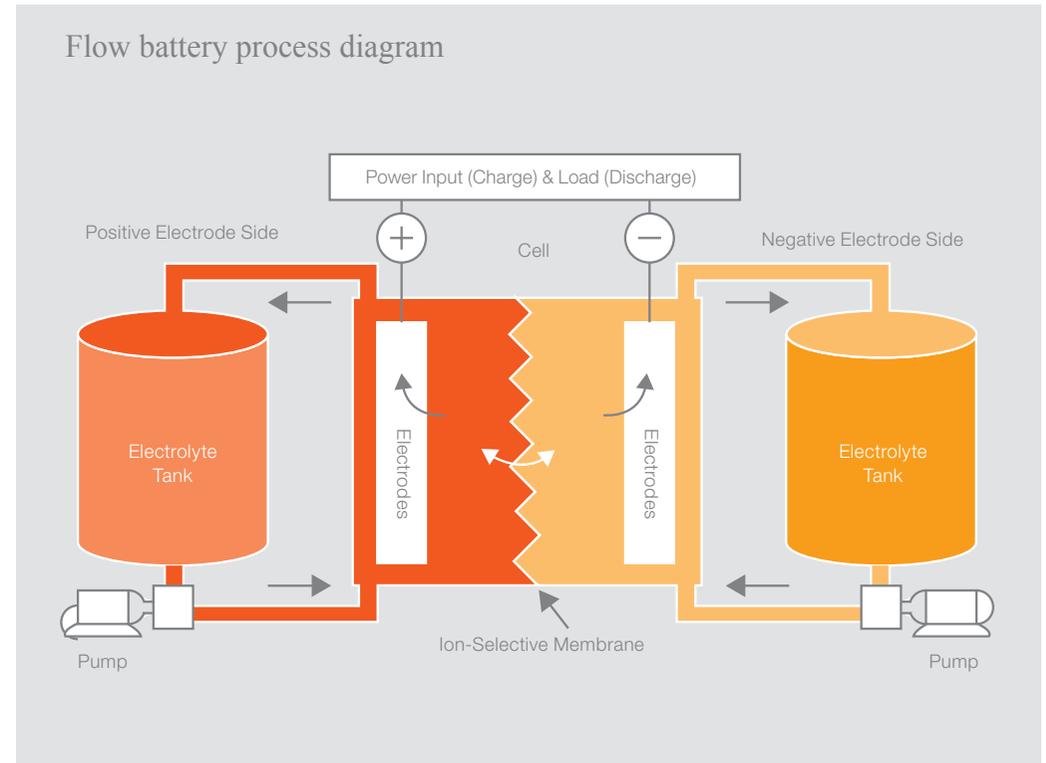
- Less sensitive to higher depths of discharge
- Able to tolerate a large number of charge/discharge cycles
- Reduced likelihood of the cells output being reduced to that of the lowest performing cell.
- Virtually unlimited capacity

Disadvantages

- Low energy density
- Not commercially mature

Applications

Flow batteries can be used for many grid applications such as: Load balancing, standby power and the integration of renewable energy sources. There are limited worldwide commercial installations to date. However, the technology has been deployed on power networks, for example a 200kW flow battery was used to store renewable energy from the Huxley Hill Wind Farm in Tasmania, the battery was operational between 2003 – 2008.



Lead Acid Batteries

Technology Description

Lead acid battery technology is the most established battery technology. There are several variants of the technology available. Flooded lead-acid batteries immerse the electrodes in liquid electrolytes and release gases upon charging. An example of this is a standard 12 volt car battery. Sealed lead acid batteries come in two forms: Absorbed glass mat batteries create energy by immobilising electrolytes with a micro fiber glass mat. Gel cell batteries have the electrolyte mixed with silica dust to form an immobilised gel. Sealed batteries do not require the regular addition of water to the cells and vent less gas than flooded lead-acid batteries. However, they have a longer re-charge time and shorter useful life. Advanced lead acid batteries have been developed and are particularly suited to energy storage applications.

Advantages

- Lead-acid batteries are an established technology, with existing infrastructure for end of life recycling already in place due to the automotive industry
- Relatively efficient
- Low self-discharge rates

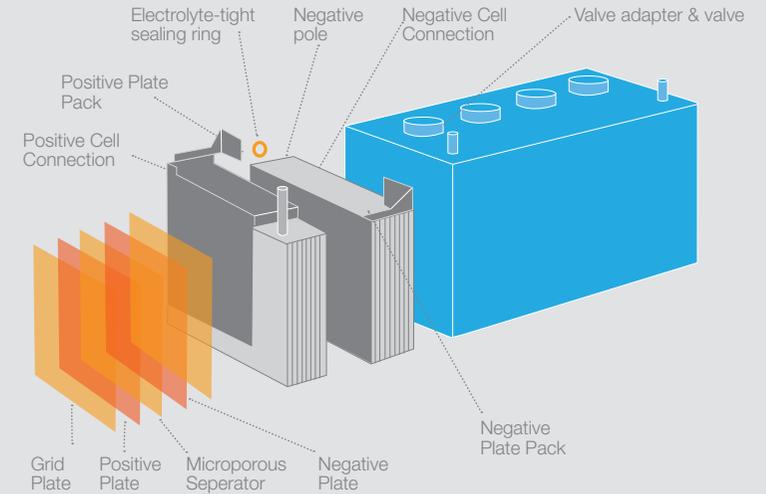
Disadvantages

- Susceptible to high depths of discharge (unless deep cycle variant)
- Low energy density
- Potentially hazardous materials

Applications

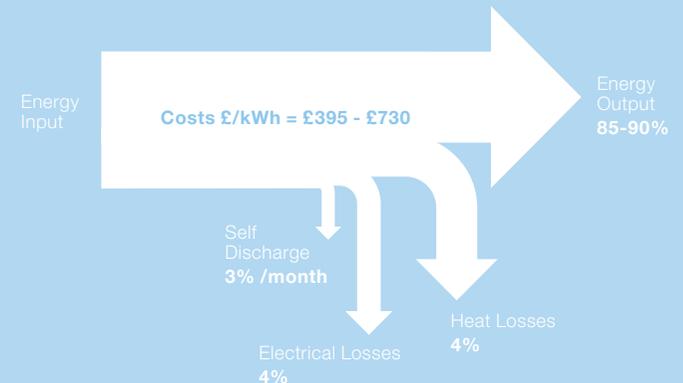
Lead acid batteries are predominantly used for starting vehicle engines as well as for backup power supplies and for grid energy storage. The technology is mature for use as ancillary service such as an Uninterruptible Power Supply (UPS), with demonstrated applications for bulk energy storage. Lead acid has been demonstrated as storing between 3 and 10 MW over a period of hours with an example being the Metlakatla lead acid battery project with an installed capacity of 1MW.

Diagram of a sealed lead acid battery



Source: Eurobat

Sankey Diagram (Advanced Lead Acid)



Lithium ion (Li-ion) Batteries

Technology Description

Lithium ion (Li-ion) batteries are a type of rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. They are commonly used in consumer electronic products, where a high energy density is required. The technology can be scaled up to distribution scale size and is commonly used in electric vehicles. The deployment of which is expected to drive down cost and improve performance. Research and development is on-going in various other chemistries of the battery type with a view to improving performance and reducing the cost.

Advantages

- Li-ion batteries have an extremely high energy density, in the order of 400 Wh/l
- Li-ion batteries are able to tolerate more discharge cycles than other technologies
- High efficiency

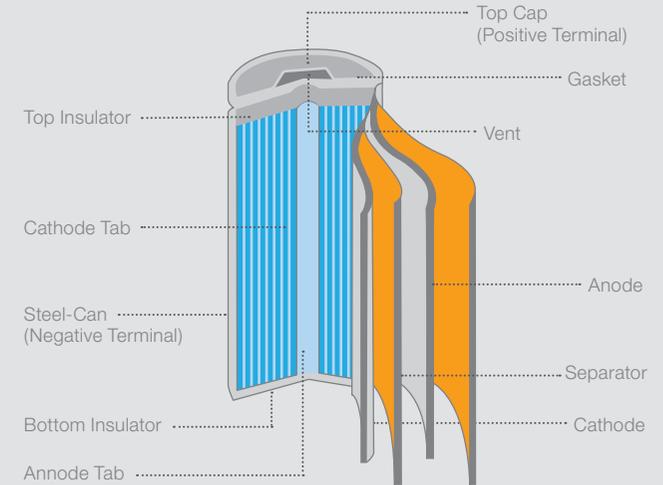
Disadvantages

- Li-ion batteries have a higher cost than other technologies
- Negative effects of overcharging/over discharging
- Potential for issues associated with overheating

Applications

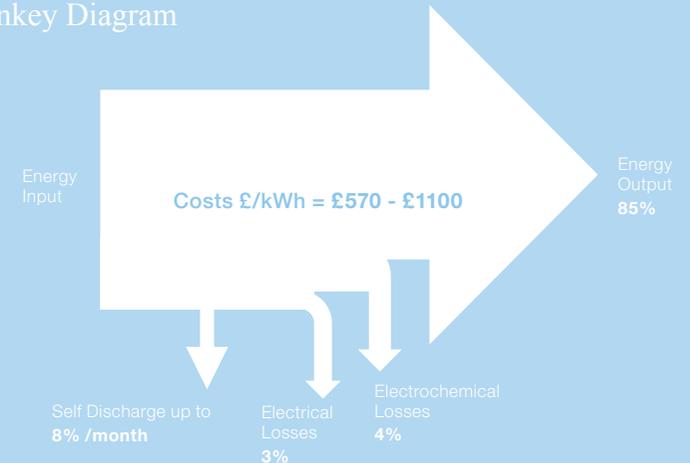
Lithium ion batteries can be used for many grid applications such as: frequency regulation, voltage regulation and the integration of renewable energy sources. There are limited worldwide commercial installations to date. However, the technology has been deployed on power networks, for example a 20MW installation was commissioned in 2011 in Johnson City, NY, USA to provide regulation services.

Diagram of a lithium-ion battery



Source: Da Vinci University

Sankey Diagram



Sodium Nickel Chloride Batteries

Technology Description

This battery chemistry consists of a nickel chloride cathode, a beta alumina separator and a liquid sodium anode. The operating temperature of the cell is between 270 C and 350°C. In charging, the sodium ions are transported through the beta alumina to the anode reservoir. Discharge is the reverse of this process. Because sodium ions move easily across the beta alumina but electrons cannot, there are no side reactions, and therefore no self-discharge. When not in use the batteries are typically left under charge so that they will remain molten and be ready for use when needed. If shut down and allowed to solidify, a reheating process is initiated before the batteries can be used again.

Advantages

- High energy density
- Long life (20 yrs)
- Little / no self discharge
- No cooling requirement
- Fully recyclable

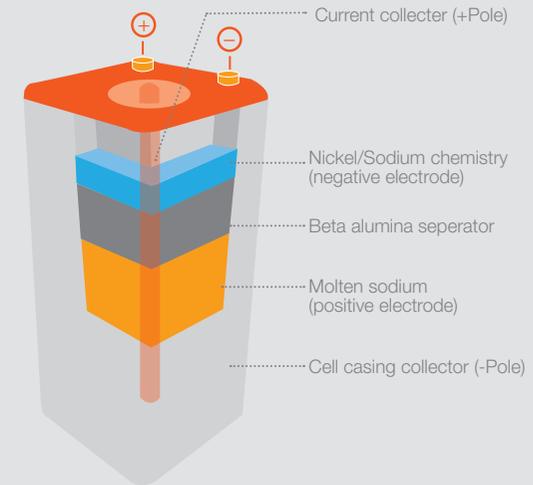
Disadvantages

- Heating may be required
- Potential safety issues with the molten sodium
- Unsuitable for short cycling

Applications

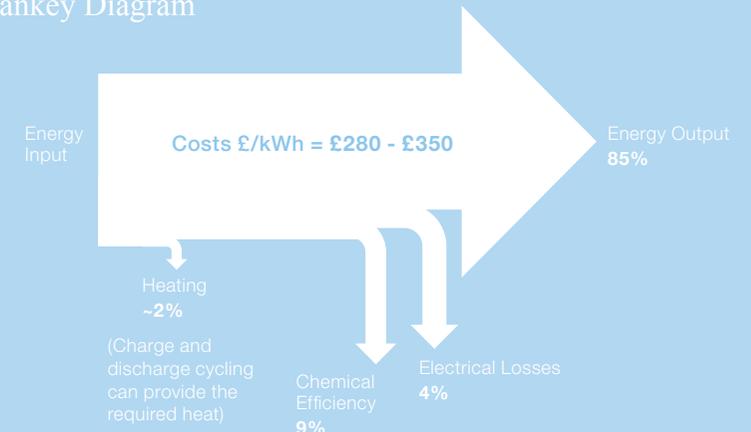
Sodium Nickel Chloride batteries can be used for many grid applications such as: asset upgrade deferral, load balancing and the integration of renewable energy sources. The technology has also been used in electric vehicles, remote telecoms systems and Uninterruptible Power Supply (UPS). There are limited grid scale installations to date, an example being a 400kW installation currently under development in Charlotte, NC, USA. This installation is investigating resolving the solar smoothing, power swing and substation capacity issues that are currently occurring on the network.

Diagram of a sodium nickel chloride battery



Source: GE

Sankey Diagram



Liquid Air Energy Storage

Technology Description

This energy storage technology uses liquid air or liquid nitrogen as the energy storage medium. Liquid air is stored in insulated low pressure tanks at cryogenic temperatures. This can either be imported to the tank by the purchase from existing supply chains or manufactured on site via a liquefaction plant. When the energy is required, the liquid air is pumped from the tank via heat exchangers to expand and drive a generating turbine. Waste heat can be applied here to dramatically increase the efficiency of the conversion process. Further efficiency gains are enabled by recycling the cold air recovered from the conversion process.

Advantages

- Not geographically constrained
- Existing global supply chain for components
- Unlimited feedstock for the energy vector

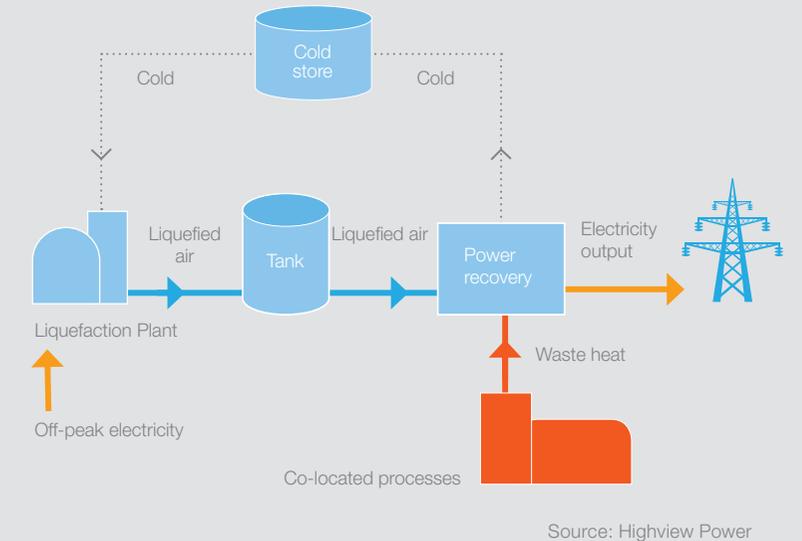
Disadvantages

- Lower efficiency unless waste heat used
- Technology currently not demonstrated in the MW scale

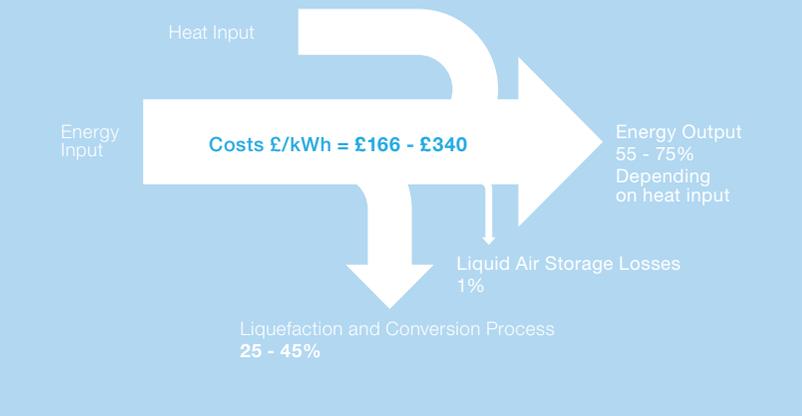
Applications

Liquid air storage can be used for many grid applications such as: energy time shifting, balancing services and the integration of renewable energy sources. There are limited grid scale installations to date, an example being a 350kW installation at Slough, UK. The installation is currently operating for the Short Term Operating Reserve (STOR) contract to provide reserve power to the grid at times when traditional generation fails. A further advantage of this technology is the ability to utilise waste heat from co-located processes and provide cool air to facilities such as data centres, reducing their peak demand.

Liquid air energy storage process diagram



Sankey Diagram



Compressed Air Energy Storage (CAES)

Technology Description

CAES involves compressing and storing air in order to store energy, either using geological underground voids or purpose made vessels. When the stored energy is needed, the released air is heated via combustion using natural gas and is expanded in order to drive a gas turbine to generate electricity.

The compression of air for storage generates heat. Current installed CAES plants are termed diabatic storage and dissipate the generated heat as waste to the atmosphere. Installed CAES installations have a similar thermal efficiency to the most efficient combined cycle gas plants and a significantly higher efficiency than open cycle gas plants.

Research is being performed into the use of adiabatic CAES. The heat generated during the compression of the gas is stored and is used for heating the compressed air prior to the expansion turbine. This heating effect could either drastically reduce or even eliminate the requirement for fuel. This technology is due to be demonstrated in Germany in 2013.

Advantages

- CAES has rapid start up times
- The mechanical system is extremely simple
- Longer asset life than technologies such as batteries

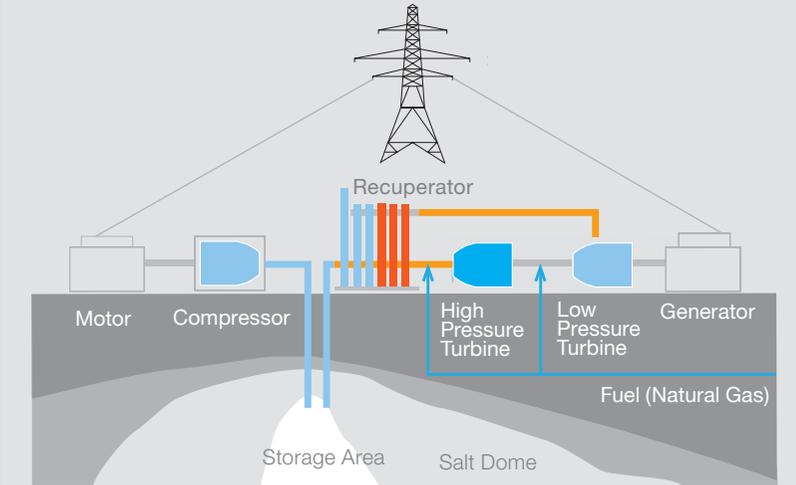
Disadvantages

- Conventional plant still requires fuel (gas)
- Current technology has a low round trip efficiency
- Can only be constructed where suitable geological features exist or requires additional infrastructure

Applications

CAES systems can be constructed in any size, provided that a suitably sized reservoir is available. Worldwide, there is approximately 400 MW of CAES capacity installed. This capacity comprises of a 290 MW scheme in Germany and a 110 MW scheme in the USA. CAES is mainly suited to load levelling applications. CAES is also particularly suited to balancing variable loads due to the rapid response time that it demonstrates.

Process example of CAES



Sankey Diagram



Pumped Hydro Energy Storage (PHES)

Technology Description

Pumped storage hydro is currently the most established utility scale method for energy storage with approximately 99% of the world's grid energy storage being pumped storage.

A pumped storage scheme uses the differential in height between two reservoirs to store energy. Pumped storage schemes can either operate using reversible pump-turbines or hydro turbines and separate pumps depending on the conditions at the site. During periods when electricity demand is lower, electricity is purchased from the grid and used to pump water from the lower reservoir to the higher one, during periods of high demand this water is released and allowed to return through the pumps now acting as turbines in order to generate electricity.

Development areas for PHES include the following:

- Underground pumped storage
- Use of the sea as lower reservoir
- Offshore energy islands

Advantages

- Mature large scale technology
- Large power and energy capacity
- Fast response times

Disadvantages

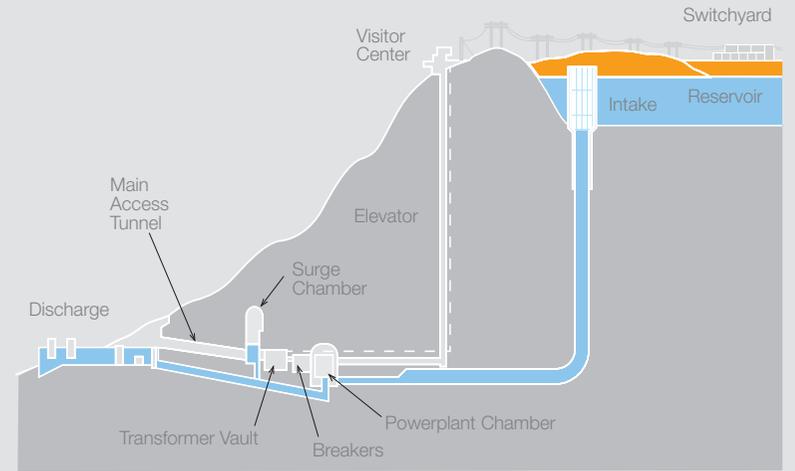
- Geographically constrained
- Limited potential for new sites (in UK)
- Away from demand centres

Applications

Pumped storage is commonly used for peak load generation, but can also be used for black starting electricity grids in the event of a complete system failure and for providing fast reserve response for grid frequency control.

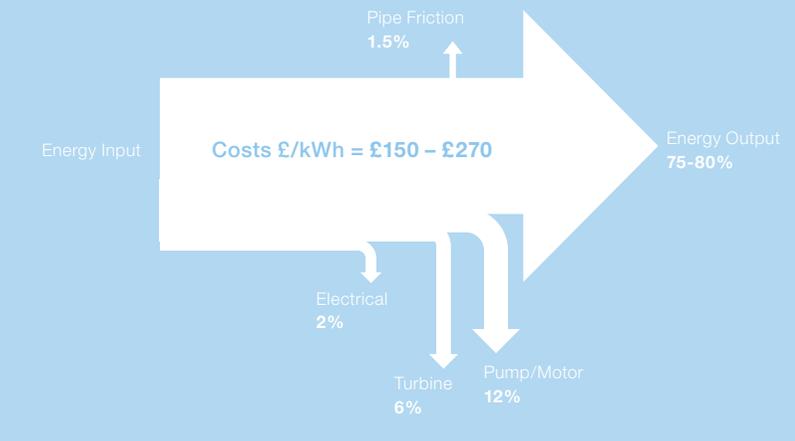
The largest pumped storage scheme in the UK, Dinorwig in North Wales can store 9.1 GWh of energy and can ramp up from zero to 1.32 GW of output in 12 seconds. Today, Dinorwig is operated not as a peaking station i.e to help meet peak loads, but rather as a STOR - Short Term Operating Reserve, or Fast Response plant, acting in response to short term rapid changes in power demand or sudden loss of power stations.

Cross section of a PHES plant



Source: TVA

Sankey Diagram



Pumped Heat Electricity Storage

Technology Description

Pumped Heat Electricity Storage (PHES) uses electricity to drive a storage engine connected to two large thermal stores. To store electricity, the electrical energy drives a heat pump, which pumps heat from the “cold store” to the “hot store” (similar to the operation of a refrigerator). To recover the energy, the heat pump is reversed to become a heat engine. The engine takes heat from the hot store, delivers waste heat to the cold store, and produces mechanical work. When recovering electricity the heat engine drives a generator.

Advantages

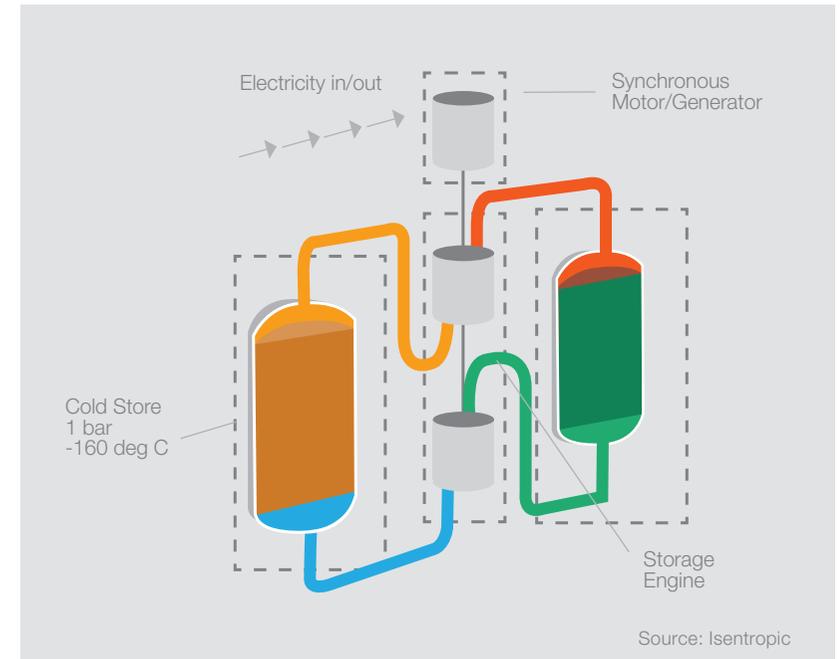
- Thermal - mechanical system with long life
- No external emissions or hazardous materials
- Virtually unlimited number of charge/ discharge cycles
- Low cost

Disadvantages

- Not commercially mature: first commercial plant expected in 2014
- Potentially large footprint

Applications

PHES can address markets that require response times in the region of minutes and upwards. The system uses gravel as the storage medium and so offers a very low cost storage solution. There are no potential supply constraints on any of the materials used in this system. Plant size is expected to be in the range of 2-5 MW per unit. Grouping of units can provide GW-sized installations. This covers all markets currently addressed by pumped hydro and a number of others that are suitable for local distribution, for example, voltage support. Technology is in development stage and commercial systems are due in 2014.



Sankey Diagram



Flywheels

Technology Description

Flywheel energy storage makes use of the mechanical inertia contained within a rotating flywheel in order to store energy. Flywheels store electrical energy by using the electrical energy to spin a flywheel (usually by means of a reversible motor/generator). In order to retrieve the stored energy, the process is reversed with the motor that accelerated the flywheel acting as a brake extracting energy from the rotating flywheel.

In order to reduce friction losses it is common to place the flywheels inside a vacuum with the actual flywheel magnetically levitated instead of using conventional bearings.

Advantages

- Rapid response times
- Low maintenance requirements
- Effective way of maintaining power quality
- Virtually unlimited number of charge/discharge cycles

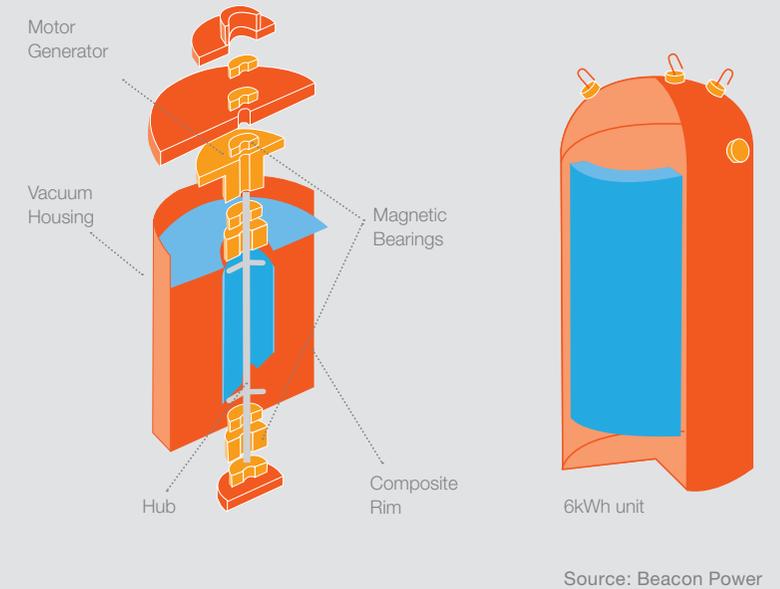
Disadvantages

- Must be housed in robust containers, in order to contain fragments if the flywheel fails
- Variable speed rotation as energy is extracted
- Requirement for precision engineered components
- High price

Applications

Flywheels as energy storage devices are more suited to improving power quality by smoothing fluctuations in generation, as opposed to having long output durations. This is because of the ability of flywheels to rapidly charge and discharge. Controlling grid frequency is an important feature and the need for this service will increase as the penetration of intermittent generating units increase. There are limited grid scale installations to date, an example being a 20 MW installation at Stephentown, New York, USA. The plant operates continuously, storing and returning energy to the grid to provide approximately 10% of the local state's overall frequency regulation needs.

Cross section of a flywheel



Sankey Diagram



Hydrogen

Technology Description

Electrical energy is stored by electrolysing water to produce hydrogen and oxygen. The oxygen is released and the hydrogen is then stored. For grid energy storage applications the hydrogen is then passed through a fuel cell that recombines the hydrogen with oxygen to produce electricity. Heat and water are also released as a byproduct.

Hydrogen gas can either be stored as a liquid at temperatures below -253°C or as a compressed gas in storage tanks.

Hydrogen use is very mature within the chemical industry. The transport and containment infrastructure for hydrogen is based on well established technologies within the supply chain. The most common method of producing hydrogen gas is the steam reformation of hydrocarbons.

Advantages

- Only emissions for using hydrogen are water vapours
- Can be transported from the point of production to the point of demand if required

- Can be used to power vehicles in addition to grid storage
- Stored hydrogen can be used any time without self discharge as with other storage technologies

Disadvantages

Low round trip efficiencies (in the region of 40%)

Low volumetric energy density

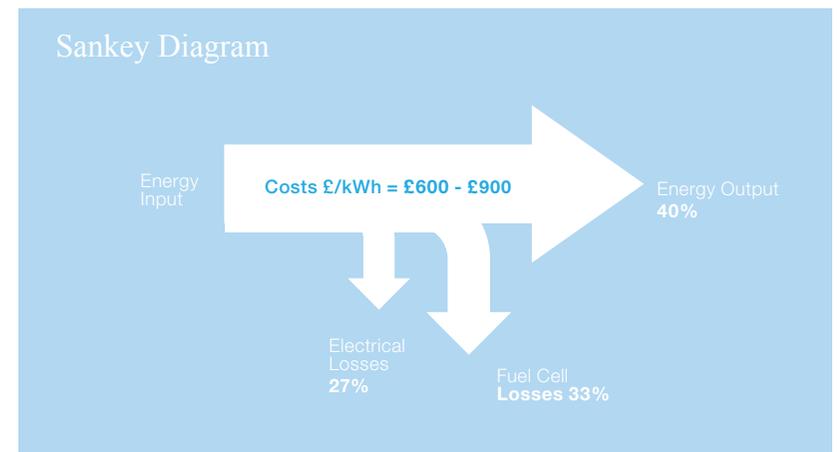
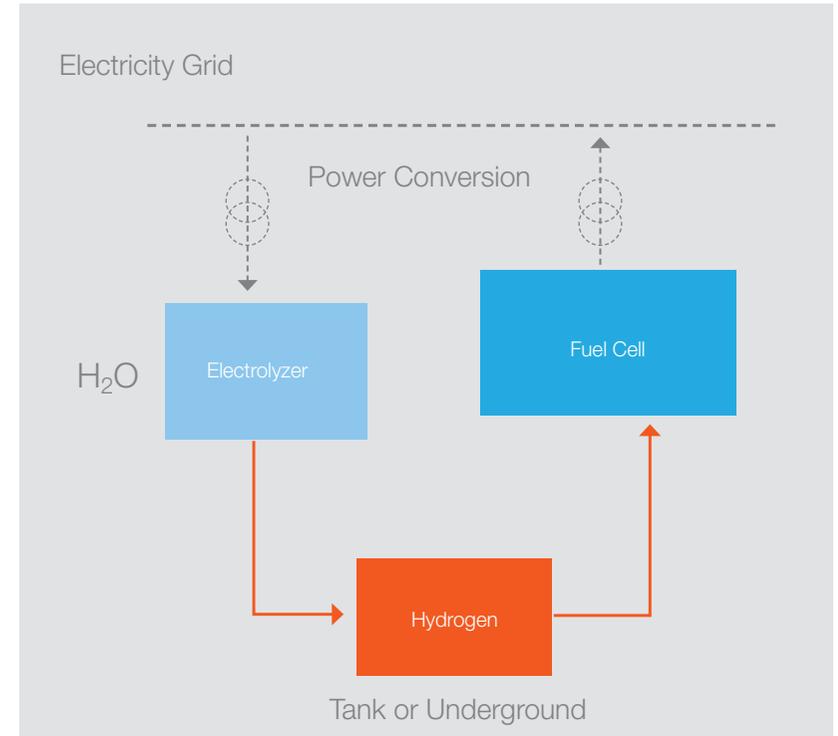
There are potential safety concerns over the storage of hydrogen

Fuel cell technologies are currently expensive

Applications

Hydrogen can either be used for grid storage or the hydrogen can be used to power vehicles. It can also be used in industrial processes.

For grid electricity storage the most efficient method of generating electricity from the stored hydrogen is by using a fuel cell.



Superconducting Magnet Energy Storage (SMES)

Technology Description

SMES systems store energy by generating strong magnetic fields within a superconducting coil. The magnetic fields are generated by a DC current flowing through the coil. The power stored in SMES systems is available almost instantaneously. The amount of energy available is independent of the discharge rating. This is in contrast to battery technology where as discharge occurs, the amount of energy output reduces.

SMES systems consist of a high inductance coil which can be treated as a constant current source. The superconducting nature of SMES means that energy can be stored for long periods of time with very little energy being lost. The most commonly used superconducting material is Niobium-Titanium (NbTi) which is operated at -271°C .

Advantages

- Ability to rapidly release stored energy
- Quick to recharge
- Almost infinite cycle life

Disadvantages

- Low energy density
- Large parasitic losses associated with the cooling of the superconducting magnet
- High cost of superconducting materials

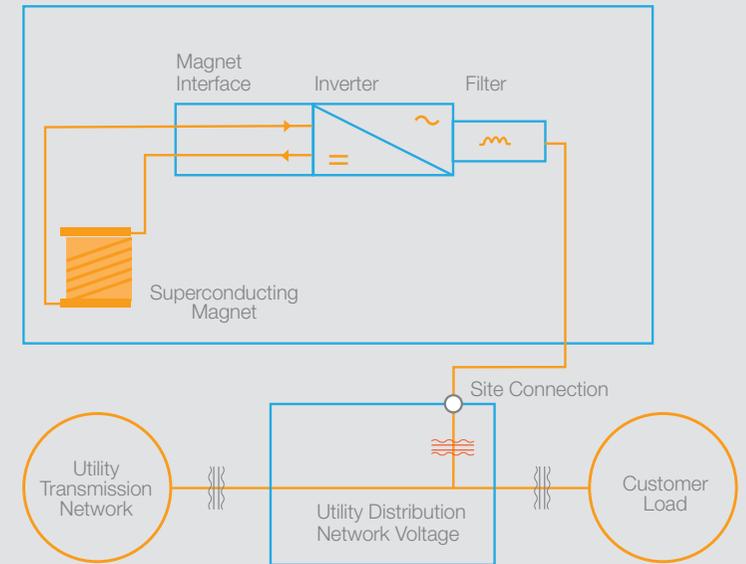
Applications

SMES are currently only used for power quality/frequency regulation applications.

There are approximately 30 SMES installations in the USA with a capacity of approximately 50 MW. An example of which is the Distributed SMES system in use in Wisconsin USA which is used for frequency regulation.

For the majority of utility scale applications, current technologies would be cost prohibitive. As the temperatures for superconducting materials increase with new discoveries, this technology could become more viable.

Distributed SMES schematic diagram



Source: EPRI

Sankey Diagram



Super Capacitors

Technology Description

Capacitors store energy as an electric charge between two plates within the capacitor. The ability of capacitors for a rapid charge and discharge cycle makes capacitors particularly suited for use for network frequency stabilisation. The current capacitor technology suited to energy storage applications is the Electric double-layer capacitor. There are other “Super Capacitor” technologies in development.

Capacitors have the potential to be used successfully in power quality applications. As the cost of capacitors reduces, the technology should become more cost effective for large scale implementation.

Advantages

- Capacitors demonstrate a virtually unlimited number of charge/discharge cycles
- Suitable for high current loads
- Extremely rapid cycle times
- Not susceptible to overcharging

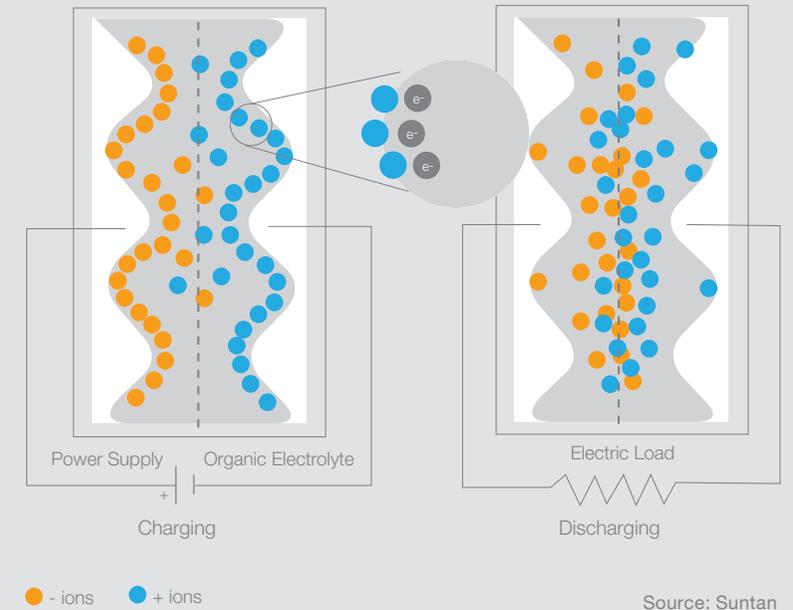
Disadvantages

- Currently expensive
- A higher rate of self-discharge makes super capacitors not suitable for longer term energy storage
- Low specific energy density

Applications

Capacitors as energy storage devices are more suited to short term storage applications, as opposed to having long output durations. Capacitors have a high level of self-discharge. They are efficient for frequent, short-duration applications. However, their efficiency for long term storage is unacceptable due to the self-discharge. There are very limited grid scale installations to date, an example being a 500 kW installation at Big Island, Hawaii. The system was used to dampen the frequency fluctuations caused by short term fluctuations in wind output.

Cross section of an electric double layer capacitor



Sankey Diagram

