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Electrical energy storage—a review of technology options

Matching uneven generation patterns to varying demands for power requires flexibility in the power network. Electrical energy storage technologies now exist to complement mature generation types as well as new forms of renewable generation. Electrical energy storage can also support network management. This paper presents examples of electrical energy storage applications, together with the development status of several technologies, and introduces the regulatory, economic and commercial aspects of combining storage with sustainable generation and operation of grid-connected and standalone power networks.

Electrical energy storage can be used for a wide range of applications on small and large networks, supporting existing and planned generation, transmission and distribution assets. Many existing power systems already use limited amounts of energy storage in their networks, mainly in the form of pumped hydroelectricity storage.

Pumped hydro is the most prevalent form of energy storage on power systems, but pressure to increase the proportion of renewable generation in power generation is leading to an opening of the market for other forms of electricity storage to be used. Coinciding with this interest is a technology push coming from many manufacturers and technology developers. New technologies in the electricity storage sector have the potential to increase and improve the proportion of energy storage on power networks.

Classification of technologies

Although electrical energy storage systems can be classified by a number of parameters such as power rating and discharge period, this paper adopts a classification by technology as shown in Table 1. Other parameters of relevance to the operation of energy storage include

- charge and discharge rates
- response time and ramp rates
- efficiency
- cycle lifetime
- calendar lifetime
- siting requirements (area, environmental, etc.)
- capital and operating costs.

Figure 1 shows the variation of power and energy ratings of different storage types and potential applications.

Electrical devices

Capacitors

There are numerous manufacturers and developers offering various types of capacitors for use in power-system applications (Fig. 2). Recent technical innovations include asymmetric construction and the use of advanced electrolytes and advanced materials. Modern high-performance capacitors can have a comparatively high energy-storage capability, with discharge periods measured in minutes rather than seconds.

However, one critical issue is the voltage of each capacitive cell. There is some concern that the high lifetimes (in the order of millions of cycles) promised by manufacturers would be difficult to achieve at a reasonable cost level.

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Nevertheless, it is likely that capacitors will continue to find applications where cycle lifetimes of 100 000 or more are required. Capacitors will always suffer from some self-discharge. Though highly efficient for frequent, short-duration cycles, their efficiency for long-term storage is thus not adequate.

Capacitive systems for energy storage are available in modular units. Typical module sizes are 50 kW with a discharge rating of 60 s. It would be feasible to connect sufficient modules together to form a 500 kW or 1 MW system.[1] Manufacturers include Safte Group, NESS, Maxwell and PowerSystem Co.

Superconducting magnetic energy storage

Superconducting magnetic energy storage (SMES) devices use the property of a superconducting material to support a moving current indefinitely as there are no resistive losses. A suitably shaped coil can be charged with electrical energy and the energy withdrawn at a later time. SMES devices have good cycle lifetimes and fast response times.

Several installations have been built—for example the Wisconsin transmission system.[2] Development work has now slowed and it seems that more attractive uses for superconductors can be found in large motors and generators instead of storage applications. The principal developer is American Superconductor (Fig. 3) although there are several other small manufacturers in Europe and Asia. The efficiency of the system is extremely high, approaching 95%, but there is a small parasitic loss required for the cooling system.

Mechanical devices

Pumped storage

Pumped storage plants are operated in many countries, totalling about 90 GW of generating capacity. Pumped storage is the most prevalent large-scale energy storage device on power systems. Typical plant sizes are 250–2000 MW with four or more hours of discharge capability.

Table 1. Storage types grouped by technology

Type	Sub-group	Examples (not exhaustive)	Typical applications
Electrical	Capacitors	Capacitors and ultracapacitors	Power quality
	Superconductors	Superconducting magnetic energy storage (SMES)	Power quality, reliability
Mechanical	Potential energy in storage medium	Pumped hydro Compressed air energy storage (CAES)	Energy management, reserve Energy management, reserve
	Kinetic energy in storage medium	Low-speed flywheels Advanced flywheels	Uninterruptible power supply Power quality
Electro-chemical	Low-temperature batteries	Lead–acid Nickel–cadmium Lithium cells	Power quality, standby power Power quality Power quality
	High-temperature batteries	Sodium–sulphur Sodium–nickel chloride	Multi-functional Standby power, remote area applications
	Flow batteries	Zinc–bromine Vanadium Polysulphide–bromine Cerium–zinc	Multi-functional Remote area applications Multi-functional —
Chemical	Hydrogen cycle	Electrolyser/fuel cell combination	—
	Other storage media	For example chemical hydrides	—
Thermal	Hot water Ceramics Molten salt / steam Ice	— — — —	Peak shaving Peak shaving Integration of renewables Peak shaving

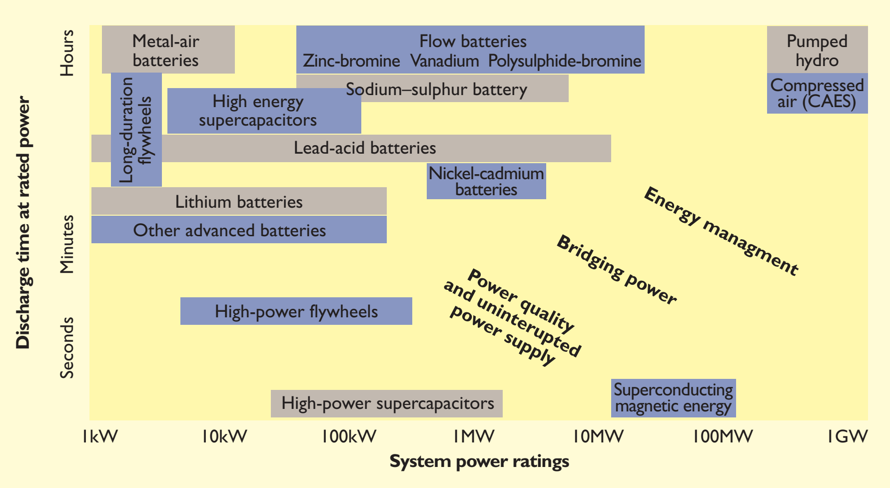

Fig. 1. Variation of power and energy ratings of different storage types and potential applications (source: Electricity Storage Association)

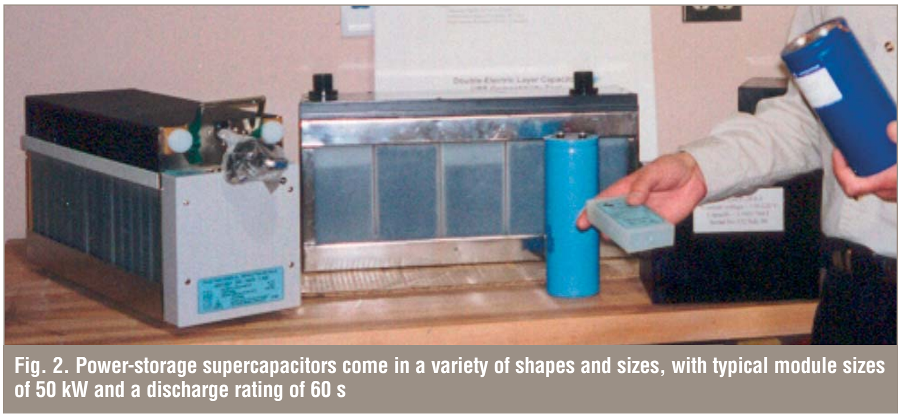

Fig. 2. Power-storage supercapacitors come in a variety of shapes and sizes, with typical module sizes of 50 kW and a discharge rating of 60 s

Fig. 3. American Superconductor truck which contains a 2 MVA superconducting magnetic energy storage system for power quality applications

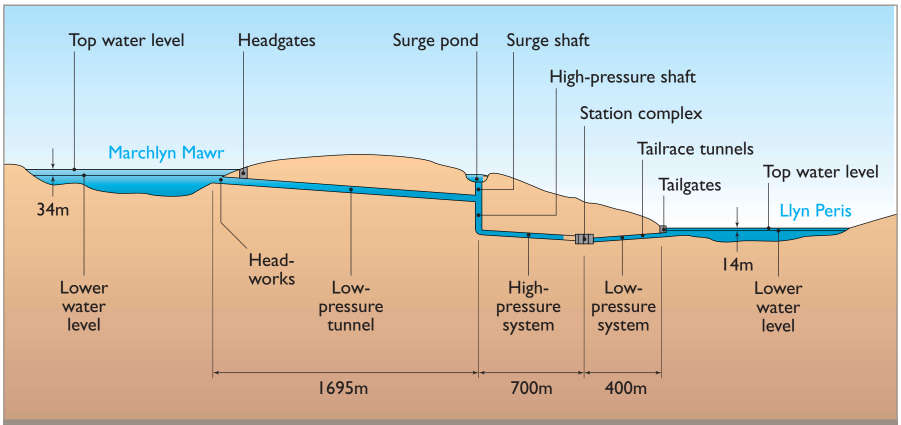

Fig. 4. Layout of the 1800 MW, 5 h Dinorwig pumped-storage scheme in North Wales (courtesy: First Hydro Company, www.fhc.co.uk)

Fig. 5. Example of a 50 kW flywheel energy storage system

The Dinorwig power station in North Wales is rated at 1800 MW, although at present two units are not operational (Fig. 4). Bath County power station in Virginia is rated at 2100 MW and was completed in 1985 at a cost of $1·7 billion. The Dneister project in Moldovia is rated at 2268 MW and was completed in 1996.

Significant advances in turbine and pump design, as well as the use of adjustable-speed machines mean that modern pumped hydro has a high operating efficiency as well as a rapid response. Recent plant can claim an 80% cycle efficiency.[3]

Flywheels

There are two main types of flywheel systems: high speed and low speed (Fig. 5). There are several developers, a number of which have made substantial progress in producing systems for uninterruptible power supplies (UPS) and improving power quality. Recently, manufacturers have claimed that flywheel systems can have relatively high-energy content and so would be useful for operation alongside renewable generation. Developers and manufacturers include Beacon Power, Active Power, Boeing and Piller.

Compressed-air energy storage

An electrically driven compressor can be used to store pressurised air in a suitable container. On a large scale, this is likely to be a salt cavern; on a small scale, steel vessels or pipework could be used. The energy can be recovered directly by passing the air through an air turbine, but it is more usual to use the air in the combustion chamber of a gas turbine. This avoids using the compressor, which would absorb about two-thirds of the turbine's output, thereby considerably enhancing its performance.

Although there is an energy storage component, it is often convenient to associate CAES as a high-performance peaking plant. There are currently two operational CAES plants (Fig. 6), although proposals are in place to see several more constructed over the coming years.

Electrochemical devices

Electrochemical devices used for power production can be grouped into two categories: non-rechargeable batteries (primary) and rechargeable batteries (secondary). Secondary batteries are good candidates for many applications because they

- have fast speeds of response—they are able to absorb or deliver energy with response times limited only by the performance of the power converter
- have high ramp rates—they are able to absorb or deliver energy with high rates of change so as to be able to follow rapid changes in the supply and demand for electricity, making makes them suitable for providing reserves such as frequency response, spinning reserve, standby reserve and black start
- can be easily sited—most battery systems are either sealed systems or enclosed with controlled emissions, therefore there are few environmental barriers to their use
- are modular—individual batteries can be replaced or the plant increased in size—many manufacturers offer a 'transportable' product that can be relocated at a future time
- have good energy efficiency, ranging from 55–80% depending on the technology.

Lead–acid batteries

The lead–acid battery, popular for its use for starting, lighting and ignition in vehicles, has been the predominant secondary battery technology. It is used in several forms such as simple flooded cells and gel-type systems and is widely available throughout the world. Small installations in remote areas may use one or

Fig. 6. The 110 MW, 26 h compressed-air energy storage plant at Macintosh, Alabama—one of only two in the world (source: EPRI)

more batteries for standby applications. Many larger systems have been constructed, including several with power ratings of more than 10 MW (Fig. 7).[4]

As far as use in power systems are concerned, lead–acid batteries tend to be used as standby batteries, either for critical systems such as telephone exchanges or for power quality applications such as computer suites. Valve-regulated batteries (VRLA) provide a low-maintenance, high-performance option and these have been used in some notable applications such as at Vernon, California and Metatlaka, Alaska. At moderate discharge rates, efficiency can approach 75%. Lead–acid batteries are likely to be the most predominant battery type for many years to come.

Nickel–cadmium batteries

Nickel–cadmium (NiCd) cells have a higher initial capital cost, but lower maintenance and a longer expected life than lead–acid batteries. A 27 MW battery system using NiCd cells was commissioned in Fairbanks, Alaska in 2003[5] as a means of providing spinning reserve power to the electricity grid (Fig. 8)

NiCd batteries have a high discharge rate and are less sensitive to higher operating temperatures than lead–acid batteries. They also perform well at low temperatures and have a flat voltage curve over the discharge period. The cycle lifetime is in excess of 3500 cycles at 80% depth of discharge.

Lithium batteries

Lithium is used in many primary and secondary battery systems in a number of different forms, and is often chosen because it is the lightest metal and has a high electrochemical reduction potential. As lithium is a highly reactive towards water it must be used with non-aqueous electrolytes.[6] Secondary lithium batteries use electrodes of lithium ions absorbed into crystal lattices of trivalent cobalt or nickel oxides together with an organic electrolyte.

The first commercial lithium-ion batteries were produced in 1991 and there are now many variations of the electrode and electrolyte materials. Some manufacturers are now producing larger cells for high-power applications.

The lithium polymer cell is a new development that uses a thin (10–100 μm) polymer electrolyte combined with special lithium electrode materials. Despite the high cost, they have attracted a significant market with a number of manufacturers producing cells for use in consumer electronic items such as mobile telephones and other telecommunication applications.

As production increases and costs drop, other bulk markets could be developed. If substantial cost reductions can be achieved, sales of lithium batteries are likely in the electric vehicle market and this may develop into high-value power-industry applications such as uninterruptible power supply (UPS) and power-quality devices. These may have applications for small-scale renewable storage systems in remote areas. Lithium battery developers include Saft, Hitachi and Valence.

High-temperature batteries

The sodium–sulphur couple using the beta-alumina electrolyte is a high-power, high-energy battery system that shows no self-discharge and has an efficiency of greater than 75%. Sodium–sulphur cells are mounted in modules that are grouped to form larger MW and MWh-size systems. The battery can also be discharged at several times its nominal power rating. For example, a battery system of 1 MW nominal output can provide peak power at 3 MW for short pulses of 30 s as well as providing load levelling at 1 MW for 7–8 h. Consequently the battery can be used for multiple applications on the power system such as local network reinforcement, improving power quality and reliability and assisting with the integration of renewable generation. A recent project for Hitachi in Japan has a power rating of 9 MW and an energy capacity of 58 MWh,[7] making it one of the largest batteries in the world for energy storage content (Fig. 9).

The sodium–nickel-chloride battery is a derivative of the sodium–sulphur battery. It also uses beta alumina as the electrolyte but the sulphur electrode is replaced by nickel chloride. The battery has been developed for the electric vehicle market and standby power applications such as UPS and support for photovoltaic installations. A typical battery configuration has a nominal voltage of 48 V and a capacity of 9·8 kWh

The sodium–sulphur battery is manufactured by NGK Insulators, and the sodium–nickel–chloride battery is manufactured by Beta R&D and MES-DEA.

Flow batteries

Flow cells—also known as redox cells, redox flow cells, redox batteries or regenerative fuel cells—have characteristics of both secondary batteries and fuel cells. In common with a secondary battery, they can be charged and discharged. Fuel

Fig. 8. This Saft 27 MW, 14 MWh nickel–cadmium battery system built in 2003 provides spinning reserve for the Golden Valley Electrical Association in Fairbanks, Alaska (source: Saft)

Fig. 7. A 1 MW, 1·2 MWh lead–acid battery installation at Stadtwerke Herne in Germany

Fig. 9. NGK-supplied 9 MW, 57 MWh sodium–sulphur peak-shaving battery for Hitachi—one of the largest energy storage batteries in the world (source: Hitachi/NKG)

cells can deliver power for as long as they are supplied with fuel and an oxidising agent. The fuel and oxidising agent react electrochemically across an ion-exchange membrane. In a similar way, flow batteries can deliver power for as long as they are supplied with charged electrolytes

Flow batteries have inert electrodes, which act only as an electron-transfer surface so the electrodes so do not limit the energy storage capacity of the flow battery. Electrical energy is stored or released by means of a reversible electrochemical reaction between two salt solutions (the electrolytes). The electrolytes are pumped through two separate electrolyte circuits and kept separate inside the cell by an ion-exchange membrane (Fig. 10).

Flow batteries have a number of advantages over conventional battery construction. One of the most important benefits is the separation of the 'power' and 'energy' properties. The power output depends on the size of the electrodes and the number of cells, while the storage capacity is determined by the size of the tanks. Usually flow batteries can be fully charged and discharged without depth of discharge limitations or memory effect. The main physical disadvantage compared to conventional battery systems is the low overall power density, usually expressed in terms of MW/m^3. Efficiencies are usually slightly lower than for conventional batteries.

The liquid electrolytes can be chosen from a wide selection of electrolytic couples on the basis of cost, availability and performance. Although many electrochemical couples are being examined, current commercial activity in flow battery systems is concentrated on four electrochemical couples: zinc–bromine, vanadium–vanadium, polysulphide–bromide and cerium–zinc.

Zinc–bromine. In contrast to other flow batteries, the zinc–bromine battery is restricted in its energy storage capacity, as the electrochemical reaction plates and removes zinc from one of the electrodes. There is therefore a physical limit to the amount of zinc that can be plated on the electrode and hence a limit to the storage capacity.

A 400 kWh system has been demonstrated on a site at Lum, Michigan for use in load management (Fig. 11). A similar project in Melbourne, Australia, has demonstrated peak shaving capabilities. An example of storage and renewable generation is being demonstrated at Greenpoint in New York where a solar panel is connected to a 100 kWh zinc–bromine battery to store energy generated over the weekend period and discharge it back to the consumer during normal working hours.[8] Manufacturers include ZBB and Premium Power.

Vanadium–vanadium. An electrochemical couple can be developed which uses the four oxidation states of vanadium, so there are vanadium oxides on both sides of an ion-exchange membrane. This offers a useful advantage in that the transfer of vanadium ions across the membrane does not inhibit the electrochemical process as may occur in other systems.

A number of systems have been built. The largest (as at October 2003) flow-battery installation has a peak power output of 3 MW[9] and a nominal rating of 1·5 MW for 1 h for load levelling. Most other installations are less than 1 MW. A 6 MW installation is currently under construction at Tomamae in Japan, which is to be linked to an operational wind farm. Manufacturers include VRB Power systems, Cellenium and the University of New South Wales.

Polysulphide–bromide. The polysulphide–bromide system used two low-cost electrolytes—sodium polysulphide and sodium bromide. Two large projects were under construction, one at Little Barford power station in Bedfordshire and a sister plant in Columbus, Mississippi. These were both of 10–15 MW rating and 120 MWh. However, design problems with the modules and storage tanks caused costs to escalate. There was also a change in ownership of the developer, a utility company, and as the development was not core business it was suspended and later sold to a developer of vanadium flow-battery systems.[10]

Cerium–zinc. Some work has been recently published on laboratory tests using the cerium and zinc couple.[11] The couple has a high cell voltage, which makes it attractive for use in flow-battery systems.[12]

Metal–air batteries

Metal–air batteries are compact and potentially low cost. The main disadvantage is that electrical recharging of these batteries is difficult and inefficient. Currently available rechargeable metal–air batteries have a life of only a few hundred cycles and an efficiency of about 50%.

The anodes in these batteries are commonly available metals with high energy density such as aluminium or zinc that release electrons when oxidised. The cathodes or air electrodes are often made of a porous carbon structure or a metal mesh covered with proprietary catalysts. The electrolytes are often potassium hydroxide, either in a liquid form or a saturated in a solid polymer membrane.

Although many manufacturers offer refuelable units where the consumed metal is mechanically replaced and processed separately, only a few developers offer an electrically rechargeable battery. While the high energy density and low cost of metal–air batteries may make them ideal for many primary battery applications, it is unlikely that these batteries will be used for applications on the power system in the near future.

The hydrogen cycle

A convenient, although not necessarily highly efficient, energy storage system can be envisaged by using an electrolyser to break water

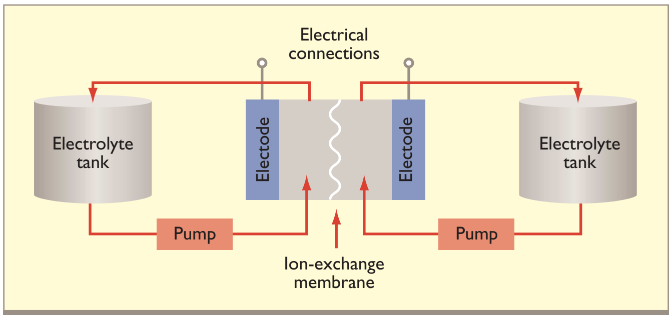

Fig. 10. Operational principles of flow batteries—power output depends on the size of the electrodes and the number of cells, while the storage capacity is determined by the size of the tanks

Fig. 11. A 400 kWh ZBB mobile zinc–bromine battery at Lum, Michigan (source: ZBB)

into hydrogen and oxygen. The hydrogen can be stored in one of three ways: as a gas, compressed as a liquid or, most likely, stored within a chemical matrix.

The hydrogen can be recombined with the oxygen using a fuel cell. It is more likely that the hydrogen cycle will be used to take advantage of hydrogen as an energy vector, rather than to take advantage of the efficiency of the storage cycle. The storage or efficient use of the oxygen produced as a by-product of the electrolysis of water should also be considered if the overall environmental and economic efficiency of the process is to be maximised. The overall electrical efficiency is low, typically below 50%.

Thermal systems

Some processes, such as building management, can be improved by using appropriate thermal methods. Ice storage is now popular in many air-conditioning installations. Hot water storage and night storage heaters are well known in the UK.

Applications of electrical energy storage

Table 2 shows examples of large energy storage systems. Electricity storage allows a discontinuity in the otherwise continuous process of generation, transmission, distribution and consumption of electricity. Stable alternating-current (AC) power systems require production to balance the consumption and the losses in transmission and distribution. If changes in either production or consumption are not matched, the frequency and voltage change—and if they are not corrected, the power system goes into collapse, often with catastrophic results. Examples occurred in Sweden, Denmark and Italy during September 2003.

By introducing storage between the generator and the consumer, surplus electricity can be stored or discharged to balance the system. The storage periods required may be in the order of cycles, minutes, hours or even days. Short pulses of power can be used to provide regulating power.

The ability of a storage plant, such as a battery, to provide power rapidly (perhaps in the order of seconds) can be used to meet rapidly changing demands. Storage can be used as means of providing reserve power, which might be considered as 'insurance' against the failure of a generating set or part of the transmission and distribution equipment.

Commercial implications of energy storage

The analysis of a proposed energy-storage system should cover all the sources of economic value or benefit that are available. Such benefits accrue not only from energy trading, but also from capacity credits and payment for reserves.

A vertically integrated utility has a structure that enables it to aggregate the benefits of storage across generation, transmission, distribution and supply. Users in only one area of the power sector may find that value streams are either denied to them or become of less value.

An energy-storage device can have a number of applications on a power network as shown in Table 3. Energy storage can increase the utilisation of the most efficient and environmentally suitable generating plants and increases the use of transmission and distribution assets. The use of energy storage as part of the power system can result in

Table 2. Examples of large energy-storage installations

Plant	Commissioned	Capacity	Applications	Comments
Lead–acid				
Electrizitatswerk, Hammermuhle, Germany	1980	400 kW 400 kWh	Peak shaving	
BEWAG, Berlin, Germany	1986	17 MW 14 MWh	Spinning reserve frequency control	Closed 1996
SCE, Chino, USA	1988	10 MW 40 MWh	Multi-purpose	Closed 1995
PREPA, Puerto Rico	1994	20 MW 14 MWh	Spinning reserve frequency control	Repowered 2004
GNB, Vernon, California, USA	1996	3·5 MW 3·5 MWh	Peak shaving and back-up power	
Un-named commercial installation, USA	2000	15 MW	Uninterrupted power supply	
Nickel–cadmium				
Golden Valley, Alaska, USA	2003	27 MW 14 MWh	Spinning reserve frequency control	Peak output 40 MW
Sodium–sulphur				
Tsuanshima	1997	6 MW 48 MWh	Load levelling	
Hitachi	2004	9 MW 57 MWh	Peak shaving	
Flow batteries				
Imajuku, Japan	1990	1 MW 4 MWh	Demonstration	
Edison, Detroit, USA	2001	400 kW 400 kWh	Demonstration	
Osaka, Japan	2001	1·5 MW 1·5 MWh	Peak shaving plus uninterrupted power supply	3 MW peak for 1·5 seconds
Pacificorp, Utah, USA	2003	250 kW 2 MWh	Peak shaving	
Compressed air				
Huntorf, Germany	1978	290 MW	Peak shaving	
Macintosh, Alabama, USA	1991	110 MW	Peak shaving	
Pumped-hydro				
Tianhuangping, China	2001	1800 MW	Load levelling	
Kazunogowa, Japan	2001	1600 MW	Load levelling	
Goldisthal, Germany	2002	1060 MW	Network applications	

Table 3. Energy-storage applications on a power network

Generation duties	Ancillary services	Transmission and distribution
Energy management	Frequency response	Voltage control
Load levelling	Spinning reserve	Power quality
Peak generation	Standby reserve	System reliability
Ramping/load following	Long-term reserve	Deferral of equipment upgrades through smoothing of power flows
Support for renewable generation		

Table 4. Suggested characteristics for storage devices in conjunction with various generation types

Generation type	Power rating	Energy rating	Comments
Wind power—small single turbine	0–50 kW	1–8 h	Isolated system in remote area
Wind power—large site	1–100 MW	8+ h	Large commercial wind farm
Solar	0–500 kW	2–4 h	Used to move energy from solar peak (noon) to system peak (4 pm or later)
Small hydro	—	—	Energy management, modulation ancillary services

- cost savings in production and distribution of each MWh
- energy supply when generation is not available
- environmental benefit, through reduction in emissions and greater incorporation of renewables.

The increased interest in renewable and sustainable generation suggests a number of specific applications. Storage could be used to ‘firm up’ the delivery of wind energy, thereby increasing its value—for example, moving it from off-peak to peak pricing periods. Storage could also be used to modulate the fluctuations in wind energy and so stabilise the network.

The application varies from storing energy for several hours, to correcting the imbalance between predicted generation and the supplied generation. This may require high power, but for relatively short periods. The imbalance may also be positive or negative (that is the storage device may need to absorb energy to correct an imbalance, as well as discharge energy). This topic is extensive as the interactions between variable generation, variable demand and the network is not simple. Some studies indicate that when there is more than about 20% wind power on a system, some form of balancing will be required.[13–16]

Consideration of wind power, solar power, small run-of-the-river hydro, tidal and wave power generation suggests that in many applications, energy storage would be useful and a viable technology. Some suggested characteristics for storage devices in conjunction with various generation types are shown in Table 4.

Suggested ratings for small run-of-the-river hydro are not given as this would be a function of the project size and type of installation (such as remote area or network connected). Storage devices are not normally required for hydro with ponding capability as the pond can store water and thus potential energy. Tidal and wave-power generation systems might be expected to use storage of up to 50% of their nominal power rating and up to 6 h energy storage capacity. It should be noted that co-locating the storage plant with the generation source is not essential. The position would be decided by considering existing and planned distribution and transmission links.

Storage, renewables and ancillary services

In order to keep a power system stable, various ancillary services are required. The frequency of the system must be kept constant (or at least within very small limits) and this requires the ability to inject or absorb real and reactive power, often within very short timescales.

Conventional fossil-fired generation can be used to provide regulating power and short- and longer-term reserve power. However as the proportion of renewable generation increases, the requirement for reserve power as a proportion of the conventional generation increases. This is unlikely to become a serious problem until variable renewable (such as wind) generation exceeds about 20% of the total generating capacity. This is rare today, but may become more significant in the future. Low-cost energy storage may be a suitable technical solution for the challenge of providing sufficient reserve power to meet network requirements when there is a high proportion of wind power on the system.

In standalone systems, such as small islands or remote areas, storage and renewable generation can be happy partners. Lead–acid batteries have been used to good effect in a number of projects in combination with renewable generation and a diesel generator. In this instance, the economic benefit is savings in fuel and diesel maintenance. The diesel engine can be run at near constant load and all modulation is provided by the battery.

The commercial mechanisms for connecting renewable generation vary from system to system, and indeed vary over time. In the UK, arrangements were made to subsidise non-fossil fuel generation through means of the Non-Fossil-Fuel Obligation (NFFO), Scottish Renewables Obligation (SRO) and Northern Ireland NFFO (NI-NFFO). The regional electricity companies were obliged to purchase the power from these projects but were reimbursed by the payment of the Fossil Fuel Levy. The current UK practice uses Renewables Obligations Certificates (ROC) to place a market-based approach to the purchase of ‘green energy’ by electricity suppliers.

The position in other countries is diverse. In Germany, network operators must purchase renewable energy at a fixed rate, which is often more expensive than the instantaneous free market price. There will be occasions when the ‘must take’ arrangement means that generation from other plants has to be curtailed to avoid overgeneration. In some parts of the USA, wind generation has to be bid into the market, and firm power receives a higher price than spot power.

Conclusions

Pumped hydro, as the traditional form of energy storage on a power network, resulted in many fine examples of large-scale civil engineering and continues to perform a valuable service in this regard. Although new pumped storage is under construction in China, Southeast Asia and in some other countries, dispersed, smaller-scale storage now provides network operators with alternative technologies which can be positioned at key points in the network and therefore will be more appropriate under many circumstances.

Network planners, those whose work includes infrastructure design and operation as well as those working with renewable forms of generation, now have access to technologies which can improve asset utilisation and increase the overall efficiency of power network operation.

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