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New technology and possible advances in energy storage ☆

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ABSTRACT

Energy storage technologies may be electrical or thermal. Electrical energy stores have an electrical input and output to connect them to the system of which they form part, while thermal stores have a thermal input and output. The principal electrical energy storage technologies described are electrochemical systems (batteries and flow cells), kinetic energy storage (flywheels) and potential energy storage, in the form of pumped hydro and compressed air. Complementary thermal storage technologies include those based on the sensible and latent heat capacity of materials, which include bulk and smaller-capacity hot and cold water storage systems, ice storage, phase change materials and specific bespoke thermal storage media.

For the majority of the storage technologies considered here, the potential for fundamental step changes in performance is limited. For electrochemical systems, basic chemistry suggests that lithium-based technologies represent the pinnacle of cell development. This means that the greatest potential for technological advances probably lies in the incremental development of existing technologies, facilitated by advances in materials science, engineering, processing and fabrication. These considerations are applicable to both electrical and thermal storage. Such incremental developments in the core storage technologies are likely to be complemented and supported by advances in systems integration and engineering. Future energy storage technologies may be expected to offer improved energy and power densities, although, in practice, gains in reliability, longevity, cycle life expectancy and cost may be more significant than increases in energy/powerdensity per se.

1. Summary of anticipated scientific and technological advances

Technology	Advances	Likelihood	Implications
Electrochemical	Incremental development of: • Electrodes • Plates • Current collectors • Seals • Membranes • Electrolytes	High	• 10–20% improvements in energy density • Enhanced cycle and chronological lifetimes • Reduced manufacturing costs
	Improved cell packaging and design	High	
	Improved battery pack make-up, thermal and electrical management	High	• Ability to construct and engineer larger battery packs • Enhanced reliability and tolerance to misuse
	Development of lithium sulphur/sulphide electrochemistries	Medium	• Potential three-fold increase in energy density
Flywheel storage	• High-performance composite fibres • Low loss, high-performance bearings • Enhanced design tools	Medium/high	• Improved energy and power densities • Reduced manufacturing costs • Enhanced reliability levels
Thermal storage	• Development of bespoke phase change materials • Improved systems integration	Medium/high	• Enhanced market application and uptake

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2. Energy storage

Energy storage embraces a wide range of energies, technologies, scales and applications. Energy may be converted to stored form in chemical, electrical, kinetic, potential or thermal media. It can be converted for final use directly, for example when heat is taken from a thermal energy store, or indirectly via an energy conversion system, for example when electricity is generated via the turbine generator of a pumped hydro storage system.

Energy storage systems are generally described as either electrical or thermal. Electrical energy storage embraces all the technologies and systems where the external interface is electrical. The energy storage medium itself may use one of a number of technologies, including electrochemical systems, kinetic energy storage and potential energy storage.

The electrical interface is an essential element of electrical energy storage systems and is provided by a power conversion system (PCS). The PCS can represent more than 25% of the overall cost of a complete electrical energy storage system.

In contrast, thermal energy storage systems utilise either the sensible or latent heat capacity of materials to provide a heating or cooling resource, which can be replenished as required.

Electrical energy storage systems find ready application in a diverse range of markets. They include traction and propulsion, the ubiquitous automotive starting, lighting and ignition (SLI) sector, standby power, remote area power supplies (RAPS) and in electrical power systems. This last-named sector is of most interest in the present paper.

In contrast, thermal energy storage has a somewhat more restricted applications domain, principally embracing the built environment, industry and certain other niche markets. Applications in the built environment are of principal interest in the context of this paper.

3. Current status: electrical energy storage

Electrical energy storage embraces a broad range of technologies, which either directly or indirectly provide electrical energy storage via an electrical input and output. The principal technologies of interest within the context of the present paper are:

- electrochemical systems (embracing batteries and flow cells),
- kinetic energy storage systems, more commonly referred to as flywheel energy storage,
- potential energy storage in the form of either pumped hydro or compressed air storage.

Further developments are in hand in relation to hydrogen storage systems in which the electrolysis of water is used to generate hydrogen to power fuel cells, but these are outside the scope of this paper.

Electrical energy storage, principally in the form of large-scale pumped hydro systems, has historically been used in electrical power systems to even out imbalances between supply and demand. For example, base load power stations can be used at times of low demand, typically at night, to charge the energy store, which can be discharged at times of peak daytime demand. Such large pumped hydro systems also provide system operators with reserve generating power that can be brought into use quickly, for example when there is a surge in TV viewer figures or when conventional power stations are unexpectedly 'tripped', or taken off the system.

Applied at a smaller scale within the power distribution network, electrical energy storage is attracting increasing interest for applications such as distribution asset deferral, peak lopping, voltage support, the assurance of power quality and the integration of renewables into power systems.

Electric power systems will need electricity storage for systems balancing if forecasts of large-scale take-up of time variable or intermittent renewables such as wind prove accurate. Energy storage can reduce the need for conventional generating plant to be kept in reserve for times when renewables are unavailable, and would involve lower carbon emissions than fossil-fuel standby plant.

Electrical energy storage technologies include some that provide short duration, high-power discharges, such as flywheels, and others that provide a bulk storage capability and which discharge over extended time periods of several hours or more, for example pumped hydro. The following sections describe the principal electrical energy storage technologies. Although complementary developments in PCS technologies also contribute to improvements in overall system performance, these are not specifically covered in the present paper.

3.1. Battery storage

Batteries are a long-established means of storing electricity in the form of chemical energy. They are classified as primary batteries, which are not rechargeable, or secondary batteries, which can be recharged. Only secondary batteries are considered in the context of the present review as primary batteries are not viable for bulk energy storage.

A battery comprises one or more electrochemical cells, with each cell comprising a liquid, paste or solid electrolyte, together with positive and negative electrodes. During discharge, electrochemical reactions at the two electrodes generate a flow of electrons through an external circuit. During the charging process, the electrochemical reactions are reversed via the application of an external voltage across the electrodes.

Battery technologies range from the mature and long-established lead-acid system (Pb-acid) through to various more recent and emerging systems and technologies, where advances are occurring in relation to sodium–sulphur, sodium–nickel chloride, and lithium ion systems. The last of these is attracting increased interest for possible use in power systems, having achieved market acceptance and uptake in consumer electronics in the so-called 3Cs sector: cameras, cellphones and computers.

Table 1 provides a summary of the essential performance characteristics of the principal battery electrochemistries currently of interest in the context of electrical power systems.

Important performance characteristics for batteries intended for use in power systems include:

- power rating and energy storage capacity,
- whole life cost,
- cycle and calendar lifetimes,
- safety and licensing considerations,
- size,
- round-trip energy efficiency level,
- operational and maintenance requirements.

3.2. Lead-acid systems

Lead-acid batteries have been used in electrical power systems for more than a century. Indeed, lead-acid accumulators were used in early municipal power systems to provide the power at night, when demand was low and the generating plant was shut down. They provide a cost-competitive and proven solution to a