

1.3.4 ENERGY STORAGE

Technology Description

Advanced storage technologies under active development include processes that are mechanical (flywheels, pneumatic), electrochemical (advanced batteries, reversible fuel cells, hydrogen, ultracapacitors), and purely electrical (superconducting magnetic storage). Energy storage devices are added to the utility grid to improve productivity, increase reliability or defer equipment upgrades. Energy storage devices must be charged and recharged with electricity generated elsewhere. Because the storage efficiency (output compared to input energy) is less than 100%, on a kilowatt-per-kilowatt basis, energy storage does not directly



A 5-MVA battery energy-storage system for power quality and peak shaving.

decrease CO₂ production. The exception to this rule is the use of advanced energy storage in conjunction with intermittent renewable energy sources, such as photovoltaics and wind, that produce no direct CO₂. Energy storage allows these intermittent resources to be dispatchable.

Energy-storage devices do positively affect CO₂ production on an industrial output basis by providing high-quality power, maximizing industrial productivity. New battery technologies, including sodium sulfur and flow batteries, significantly improve the energy and power densities for stationary battery storage as compared to traditional flooded lead-acid batteries.

System Concepts

- **Utilities:** The efficiency of a typical steam plant falls from about 38% at peak load to 28%-31% at night. Utilities and customers could store electrical energy at off-peak times, allowing power plants to operate near peak efficiency. The stored energy could be used during high-demand periods displacing low-efficiency peaking generators. CO₂ emissions would be reduced if the efficiency of the energy storage were greater than 85%. Energy storage also can be used to alleviate the pressure on highly loaded components in the grid (transmission lines, transformers, etc.) These components are typically only loaded heavily for a small portion of the day. The storage system is placed downstream from the heavily loaded component. This reduces electrical losses of overloaded systems. Equipment upgrades also are postponed, allowing the most efficient use of capital by utility companies.
- **Industrial:** The operation of modern, computerized manufacturing depends directly on the quality of power the plant receives. Any voltage sag or momentary interruption can trip off a manufacturing line and electronic equipment. Industries that are particularly sensitive are semiconductor manufacturing, plastics and paper manufacturing, electronic retailers, and financial services such as banking, stock brokerages, and credit card-processing centers. If an interruption occurs that disrupts these processes, product is often lost, plant cleanup can be required, equipment can be damaged, and transactions can be lost. Any loss must be made up decreasing the overall efficiency of the operation, thereby increasing the amount of CO₂ production required for each unit of output. Energy-storage value is usually measured economically with the cost of power-quality losses, which is estimated in excess of \$1.5 B/year in the United States alone.

Industry is also installing energy-storage systems to purchase relatively cheap off-peak power for use during on-peak times. This use dovetails very nicely with the utilities' interest in minimizing the load on highly loaded sections of the electric grid. Many energy-storage systems offer multiple benefits. (An example is shown in the photo.) This 5-MVA, 3.5-MWh valve-regulated lead-acid battery system is installed at a lead recycling plant in the Los Angeles, California, area. The system provides power-quality protection for the plant's pollution-control equipment, preventing an environmental release in the event of a loss of power. The system carries the critical plant loads while an orderly shutdown occurs. The battery system also in discharged daily during the afternoon peak (and recharged nightly), reducing the plant's energy costs.

Representative Technologies

For utilities, the most mature storage technology is pumped hydro; however, it requires topography with significant differences in elevation, so it's only practical in certain locations. Compressed-air energy storage uses off-peak electricity to force air into underground caverns or dedicated tanks, and releases the air to drive turbines to generate on-peak electricity; this, too, is location specific. Batteries, both conventional and advanced, are commonly used for energy-storage systems. Advanced flowing electrolyte batteries offer the promise of longer lifetimes and easier scalability to large, multi-MW systems. Superconducting magnetic energy storage (SMES) is largely focused on high-power, short-duration applications such as power quality and transmission system stability. Ultracapacitors have very high power density but currently have relatively low total energy capacity and are also applicable for high-power, short-duration applications. Flywheels are now commercially viable in power quality and UPS applications, and emerging for high power, high-energy applications.

Technology Status - Utilities

Technology	Efficiency [%]	Energy density [W-h/kg]	Power density [kW/kg]	Sizes [MW-h]	Comments
Pumped hydro	75	0.27/100 m	low	5,000-20,000	37 existing in U.S.
Compressed gas	70	0	low	250-2,200	1 U.S., 1 German
SMES	90+	0	high	20 MW	high-power applications
Batteries	70-84	30-50	0.2-0.4	17-40	Most common device
Flywheels	90+	15-30	1-3	0.1-20 kWh	US & foreign development
Ultracapacitors	90+	2-10	high	0.1-0.5 kWh	High-power density

System Components

Each energy-storage system consists of four major components: the storage device (battery, flywheel, etc.); a power-conversion system; a control system for the storage system, possibly tied in with a utility SCADA (Supervisory Control And Data Acquisition) system or industrial facility control system; and interconnection hardware connecting the storage system to the grid. All common energy-storage devices are DC devices (battery) or produce a varying output (flywheels) requiring a power conversion system to connect it to the AC grid. The control system must manage the charging and discharging of the system, monitor the state of health of the various components and interface with the local environment at a minimum to receive on/off signals. Interconnection hardware allows for the safe connection between the storage system and the local grid.

Current Research, Development, and Demonstration

RD&D Goals

- Utilities require high reliability, and costs less than or equal to those of new power generation (\$400–\$600/kW). Compressed gas energy storage can cost as little as \$1-\$5/kWh, while pumped hydro ranges from \$10-\$45/kWh. Battery storage systems range from \$300-\$2000/kW.

RD&D Challenges

- The major hurdles for all storage technologies are cost reduction and developing methods of accurately identifying all the potential value streams from a given installation. Advanced batteries need field experience and manufacturing increases to bring down costs. Flywheels need further development of fail-safe designs and/or lightweight containment. Magnetic bearings could reduce parasitic loads and make flywheels attractive for small uninterruptible power supplies and possibly larger systems using multiple

individual units. Ultracapacitor development requires improved large modules to deliver the required larger energies. Advanced higher-power batteries with greater energy storage and longer cycle life are necessary for economic large-scale utility and industrial applications.

RD&D Activities

- The Japanese are investing heavily in high-temperature, sodium-sulfur batteries for utility load-leveling applications. They also are pursuing large-scale vanadium reduction-oxidation battery chemistries. The British are developing a utility-scale flow battery system based on sodium bromine/sodium bromide chemistry. DOE’s Energy Storage Systems Program works on improved and advanced electrical energy storage for stationary (utility, customer-side, and renewables) applications. It focuses on three areas: system integration using near-term components including field evaluations, advanced component development, and systems analysis. This work is being done in collaboration with a number of universities and industrial partners.

Commercialization and Deployment Activities

- For utilities, only pumped hydro has made a significant penetration with approximately 37 GW.
- Approximately 150 MW of utility peak-shaving batteries are in service in Japan.
- Two 10-MW flow battery systems are under construction – one in the United Kingdom and the other in the United States.
- Megawatt-scale power quality systems are cost effective and entering the marketplace today.