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Overview on different types of energy storages.

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TECHNICAL REPORT

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Overview on different types of energy storages

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RESULT (summary)

Electrochemical capacitors have low specific energy, but very good specific power, and are applicable for power pulse durations between 0.01-100 s. Typical applications are power quality related problems, UPS applications and transmission line stability, and as a complementary storage with batteries, fuel cells and diesel electric systems.

Batteries are very diverse in characteristic and application. Well-known technology like lead-acid and nickel-cadmium are used in large battery energy storages (tens of MWh). Flow batteries (Regenesys, Redox and Zinc/Bromine) are promising for very large-scale storages (>100 MWh). High temperature sodium-sulfur batteries (NaS) are also installed in some MWh-plants. New technology like Li-ion batteries shows promising characteristics, but is not mature for larger energy storage application. Lead-acid is a clear winner on initial cost, followed by NiCd and then NiMH and at last Li-ion. Li-ion is not inherently expensive: Cost is very volume sensitive. (Metal-air batteries are the least expensive alternative, but are not mature for energy storage applications with electrical recharge.) In addition, flow batteries are cost effective in very large-scale energy storages.

Life cycle cost is more important in energy storage than initial costs. It is therefore important to consider effect of operating conditions on life. Main influence comes from temperature and cycling. (E.g. lead acid batteries shorten their lifetime with 50 % for every 8˚C increase, while NiCd only cuts by 20 %.)

Flywheels are appropriate for time durations up to some minutes and energy densities in the kWh-range. Low-speed flywheels are commercial available, while high-speed solutions with higher energy densities are limited. Applications like battery replacements in UPS are reported. The initial cost of low-speed flywheels is rather low, and they can be an alternative to batteries at low energy ratings.

SMES applications are short-time, high power pulses, like power quality improvements in industrial plants or voltage/VAR support and transmission stability in utility transmission lines. Their maturity and availability is limited (one commercial manufacturer worldwide), and they are expensive: For most application, investment costs and losses are too high compared with other storage devices. Diurnal load leveling is not a cost-effective application for SMES now or in the long term.

KEYWORDS

SELECTED BY AUTHOR(S)	energy storage	electrochemical energy storage
	flywheel	superconducting magnetic energy storage

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1 SUMMARY

Based on a literature study, four different energy storage technologies are reviewed: Electrochemical capacitors, batteries, flywheels and superconducting magnetic energy storages (SMES). The presentation is general, but emphasizes stationary applications. Portable (consumer) electronics and vehicle specific applications are not included.

The applicability of different energy storages is strongly influenced by the application. A general presentation relating the power and energy rating with the duration of the pulse is shown in table 1.1.

Table 1.1: Different energy storages and their applications

Energy storage		Typical power rating [MW]	Typical discharge time	Application
Electrochemical capacitor		0,0001-0,1	seconds to minutes	Power quality, UPS, complementary storage to batteries, fuel cells, diesel electric etc.
Battery	Lead acid	0.001-50	minutes to hours	Power quality, reliability, frequency control, reserve, black start, UPS
	Advanced (VRLA, NaS, Li)	0,001-1	minutes to hours	Various, including utility energy storage
	Flow batteries	0,1-100	minutes to tens of hours	Power quality, reliability, peak shaving, reserve, energy management, integration of renewables
Flywheel		0,005-1,5	seconds to minutes	Power quality, battery replacement in UPS
SMES		0,01-2	≤ seconds	Transmission stability, voltage/VAR support, power quality

Table 1.2 shows typical characteristics of the different energy storages

Table 1.2: Typical characteristics of different energy storages.

Energy storage	Energy density		Power density		Efficiency	Life time	Recharge time	Maintenance	Maturity
	[Wh/kg]	[Wh/dm^3]	[W/kg]	[W/dm^3]	[%]	[cycles|years]			
Electrochemical capacitors	1-10	0,01-20	400-4000	10^2-10^6	90-95	>10^5|>10	Seconds to minutes	None	Good, increasing
Batteries	10-200	10-400	20-600	10-1000	50-95	500-10^4|2-20	Minutes to hours	From weeks to none	Very good
Flywheels	30-200	1-?	180-30000	125-667	88-93	10^5|20	Minutes	Months to annual	Good/modest, increasing
SMES	4 –75	-	10^3-10^5	-	90-99	>10^5|20	Minutes (μ-SMES)	Annual	Poor, increasing slowly

Table 1.3 shows availability, costs and environmental aspects.

Table 1.3: Availability, cost and environmental impact. (Guidelines only)

Energy storage		Capital costs [$/kWh | $/kW]	Availability	Environmental impact
Electrochemical capacitors		83500 | 250-1000	Good	Very good
Battery	Lead acid	200-700 | 240-700 [1)]	Very good	Modest to very good Depending on type of battery. (Future ban of cadmium?)
	Advanced (VRLA, NaS, Li)	Very varying dependent of technology, but always more expensive than lead-acid	Good to very good (depending on technology)	
	Flow batteries	175-600 | -	Modest	
Flywheel		300-25000 | 300-500	Low-speed flywheel available High-speed flywheel hardly available	Good. Uncertainty: Safety problem on mechanical damage of rotor?
SMES		~2,4 million | ~670	Poor. One manufacturer worldwide	Good (Magnetic field in surroundings of superconductor. Possible health effect?)

1) Based on cost of plants >1MW in the world in 1995 (1995$)

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Batteries are very diverse in characteristic and application. Well-known technology like lead-acid and nickel-cadmium are used in large battery energy storages (tens of MWh). Flow batteries (Regenesys, Redox and Zinc/Bromine) are promising for very large-scale storages (>100 MWh). High temperature sodium-sulfur batteries (NaS) are also installed in some MWh-plants. New technology like Li-ion batteries shows promising characteristics, but is not mature for larger energy storage application.

A graphical presentation of some battery comparisons are given below:

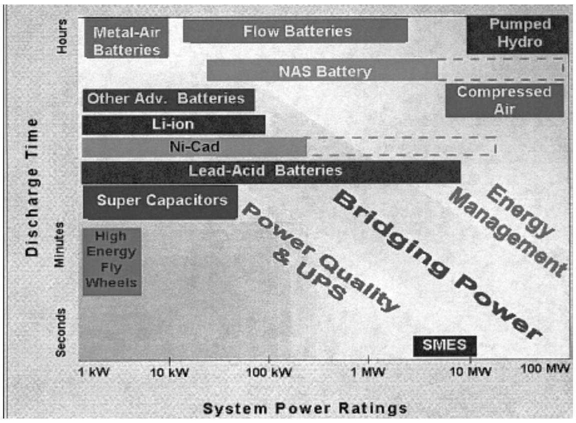

Figure 1.1 Guidelines for typical applications of energy storages plotted in a diagram of discharge time vs. system power rating

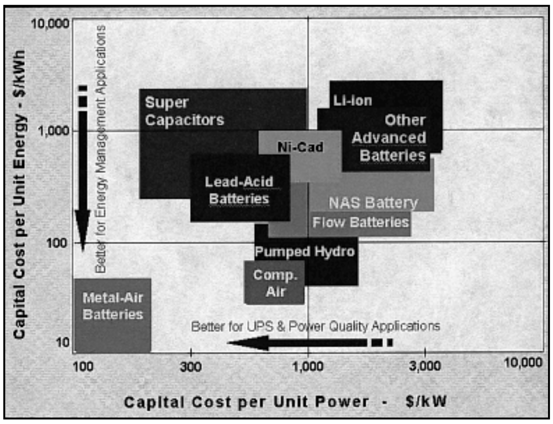

Figure 1.4 Capital cost comparisons for different energy storage techniques.

Lead-acid is a clear winner on initial cost of different battery technologies, followed by NiCd and then NiMH and at last Li-ion. Li-ion is not inherently expensive: Cost is very volume sensitive. (Metal-air batteries are not mature for energy storage applications with electrical recharge.) In addition, flow batteries are cost effective in very large-scale energy storages.

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The figures in this report vary over a wide range, since different literature sources are not necessarily compatible. In order to get more precise information, two different approaches are possible:

- Inquiry to manufacturers (Technical questions, costs questions etc.)
- Visit manufacturers, research organisations or highly skilled users with experience from usage of the different energy storages.

If inquiry to manufacturers is done, it is important to make sure that the answers easily can be compared. This can be achieved if the questions are related to an installation or application, where the necessary requirements are specified.