Renewable Energy & Hydroelectric Works

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Energy storage

A. Efstratiadis, I. Tsoukalas, G.-K. Sakki, N. Mamassis & D. Koutsoyiannis

Department of Water Resources & Environmental Engineering, NTUA

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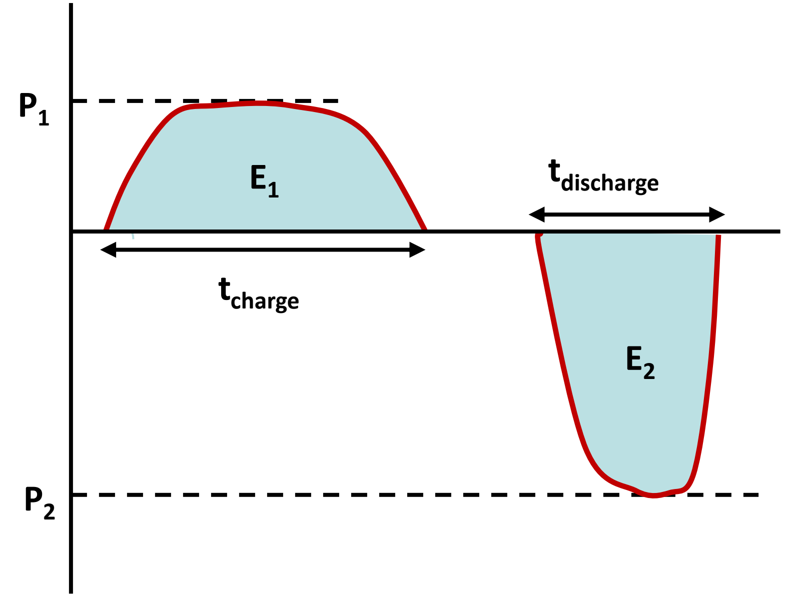
The concept of electrical energy storage (EES)

- Electricity cannot itself be stored on any scale, but it can be **converted to other forms of energy** which can be stored and later reconverted to electricity on demand.
- Based on the mechanism used, energy storage systems can be classified into **electrochemical**, **chemical**, **electrical**, **thermal** and **mechanical**.
- EES objectives:
    - regulating **imbalances** between energy demand and energy production;
    - lowering **electricity supply costs** by storing energy at off-peak rates;
    - improving **reliability** at times of unexpected failures or disasters;
    - maintaining and improving **power quality** across the grid (frequency, voltage).
- All types of EES induce **power losses** within **conversion** and due to **self-discharge** effects
- **Generic principles:**
    - Charge during low-demand periods and discharge to fulfill peak demand;
    - Multiple technologies with different characteristics in terms of efficiency, response time, etc.
    - Key issue is the time scale (short, long)



Pumped hydropower storage (PHPS)

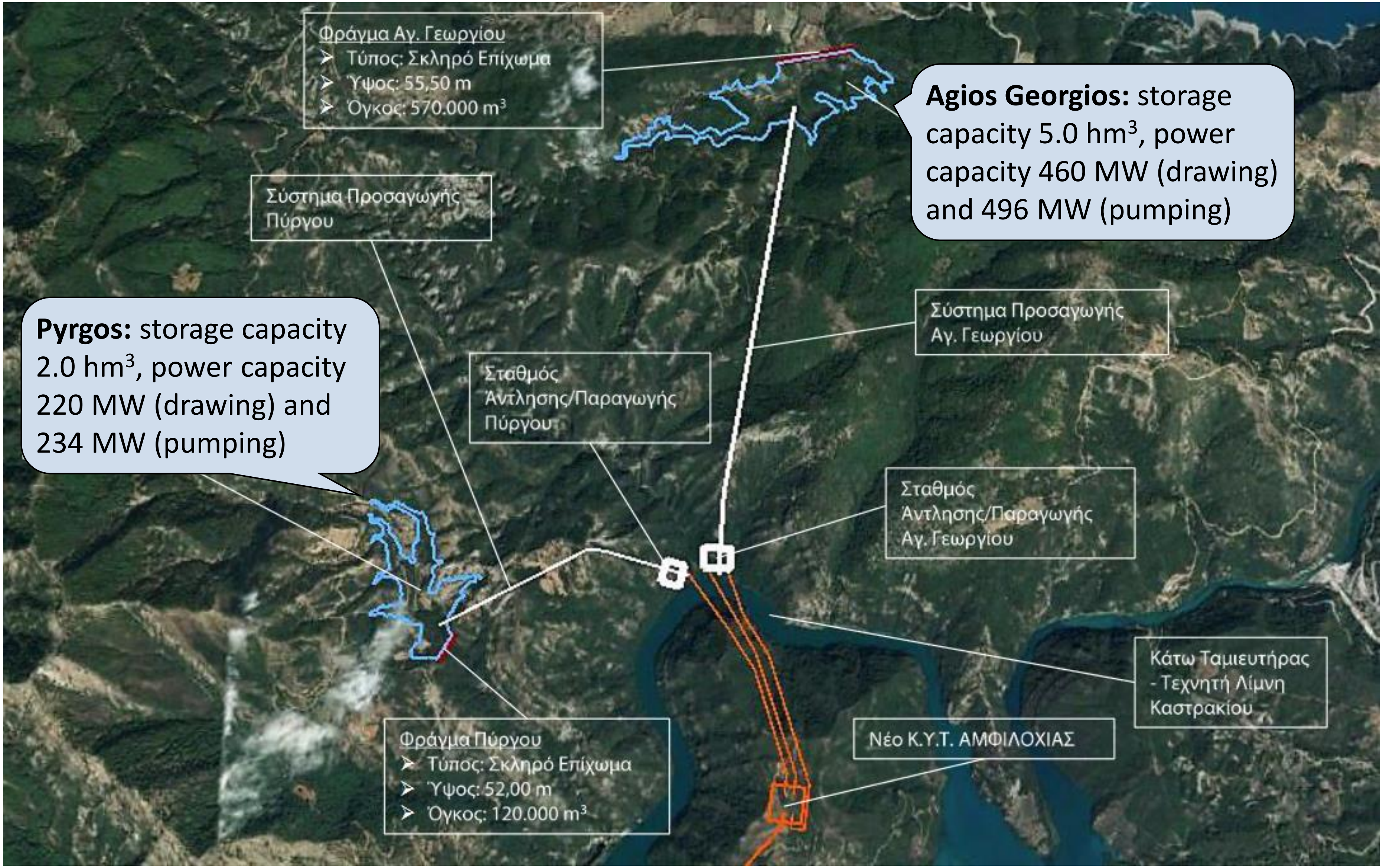
- Mature technology, covering >95% of total in-service electricity capacity over the globe (total installed capacity >180 GW, total energy storage capacity over 1.6 TWh).
- Classified into two main categories:
  - **Open loop systems**: coupled to a natural water system, where the lower reservoir is connected to a river
  - **Closed loop systems**: two independent reservoirs or tanks (upper, lower)
- Key element is a **pump hydro turbine** or **reversible pump turbine** (typically Francis-type), utilized as pumps during charging to lift water from the lower to the higher reservoir, and operating as turbines during peak demand to generate hydropower.
- Round-trip **energy recovery** (effect of combined turbine/pump efficiency): 70-80%
- Their ability of **rapid change** make them ideal for electricity generation and storage and for handling electrical grid fluctuations.
- Traditionally used to **regulate excess electricity** from continuous base-load sources (e.g., coal or nuclear), to be saved for periods of higher demand.
- The role of pumped storage hydropower plants is twofold, i.e. balancing the grid for **demand driven fluctuations**, and balancing **generation-driven fluctuations**.
- Their implementation is expected to increase because of the **integration of intermittent, non-dispatchable renewable energy sources** to the electricity mix.

Examples

Presenzano, Italy: Two reservoirs of equal storage capacity (6.0 hm^3), power capacity 1000 MW (four Francis-type pump-turbine generators), gross head 495 m; construction began in 1979, finished in 1990, generators commissioned in 1991

Tumut 3: First major pumped-storage station in Australia (constructed in 1968, entered into operation in 1972, upgraded in 2012); six turbines of combined power capacity of 1800 MW, three of them also operate as pumps; rated head 150.9 m; six pipelines of 488 m length and 5.6 m and diameter; lower storage element: Talbingo reservoir (920 hm^3), upper element: Jounama reservoir (43.5 hm^3)

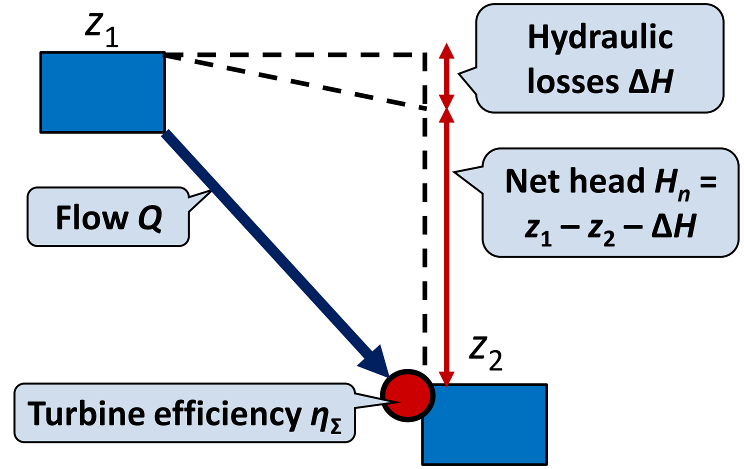
Hydro Pumped Storage Complex, Amfilochia



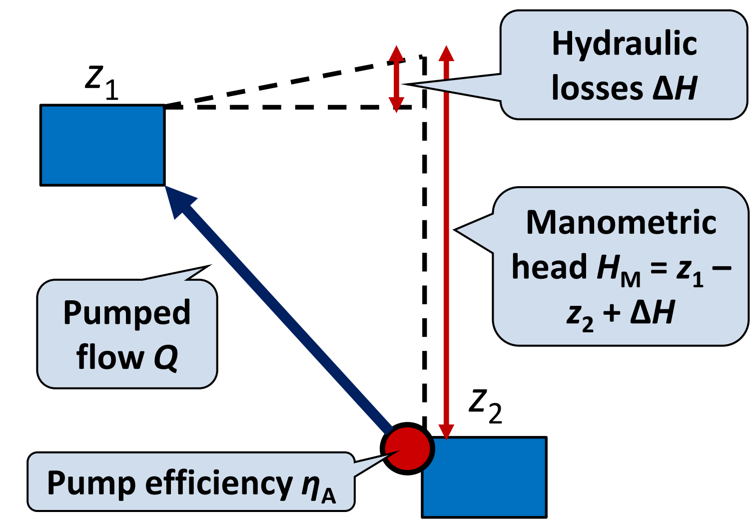
Source: http://hps-amfilochia.gr/wp-content/uploads/2016/11/HPS_Amfilochia_Project-Synopsis_Revised_Sep2016.pdf; https://www.terna-energy.com/acivities/pumped-storage-projects/amfilochia-pumped-storage/

Design challenges

- The reservoirs are quite small when compared to conventional hydroelectric dams of similar power capacity, while the generating periods are often less than half a day.
- Typical layout: utilizing an existing reservoir (either upper or lower), and forming another one (much smaller, typically for daily to to weekly regulation);
- A reversible power station is settled between the two reservoirs;
- Requires small fluctuation of the water level;
- Minimizing of horizontal distance and maximizing the vertical distance of the two reservoirs, to ensure **large heads** and **minimal hydraulic losses**;
- Minimizing impacts on existing plant;
- Specific case: application of two independent pipes for simultaneous production and storage (beneficial for regulating highly fluctuating renewable energy sources, particularly wind).

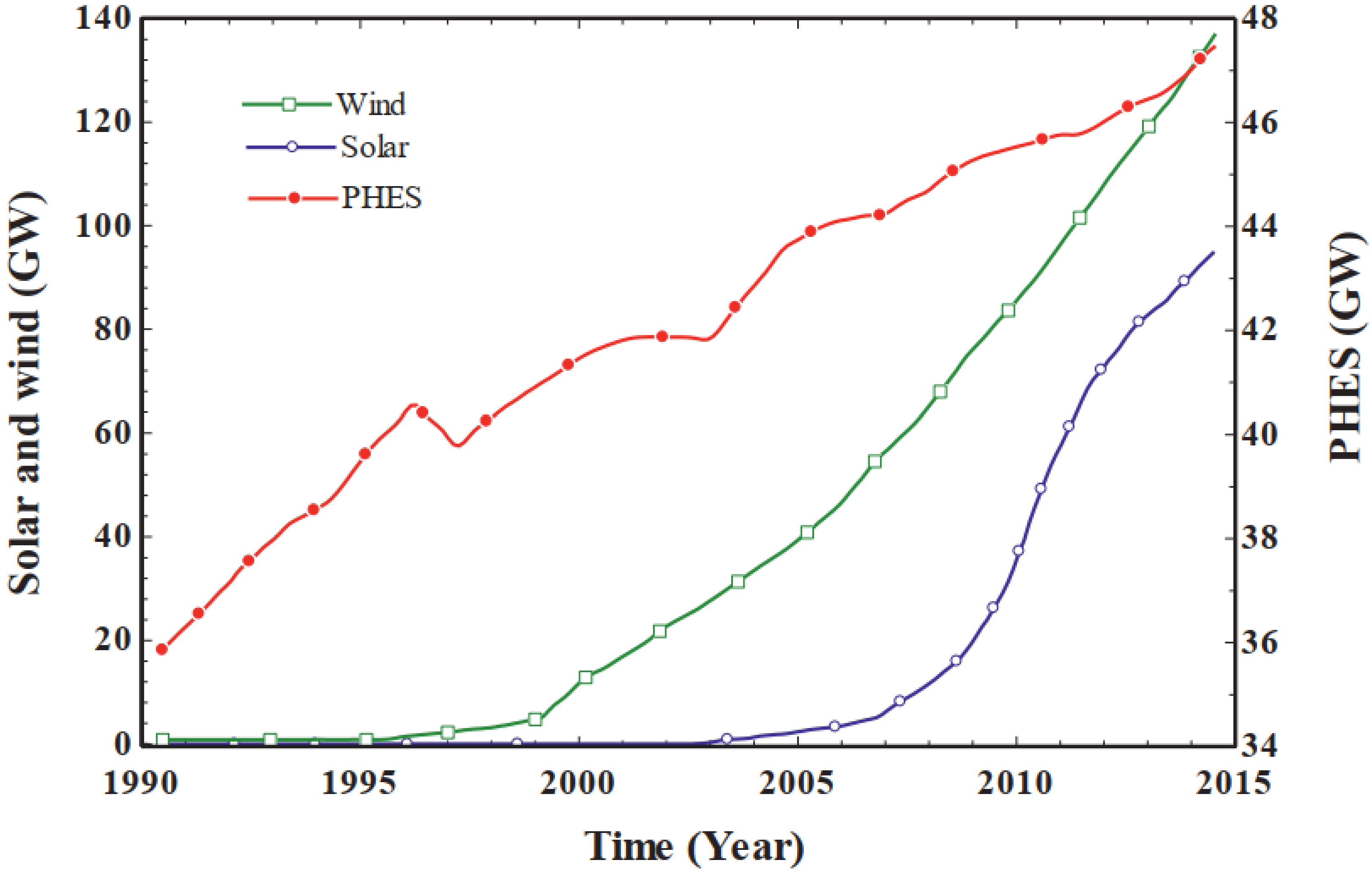


Power production: $P = \eta_\Sigma \gamma Q (\Delta z - \Delta H)$



Power consumption: $P = \gamma Q (\Delta z + \Delta H) / \eta_A$

Progress of PHES, solar and wind capacity in EU28

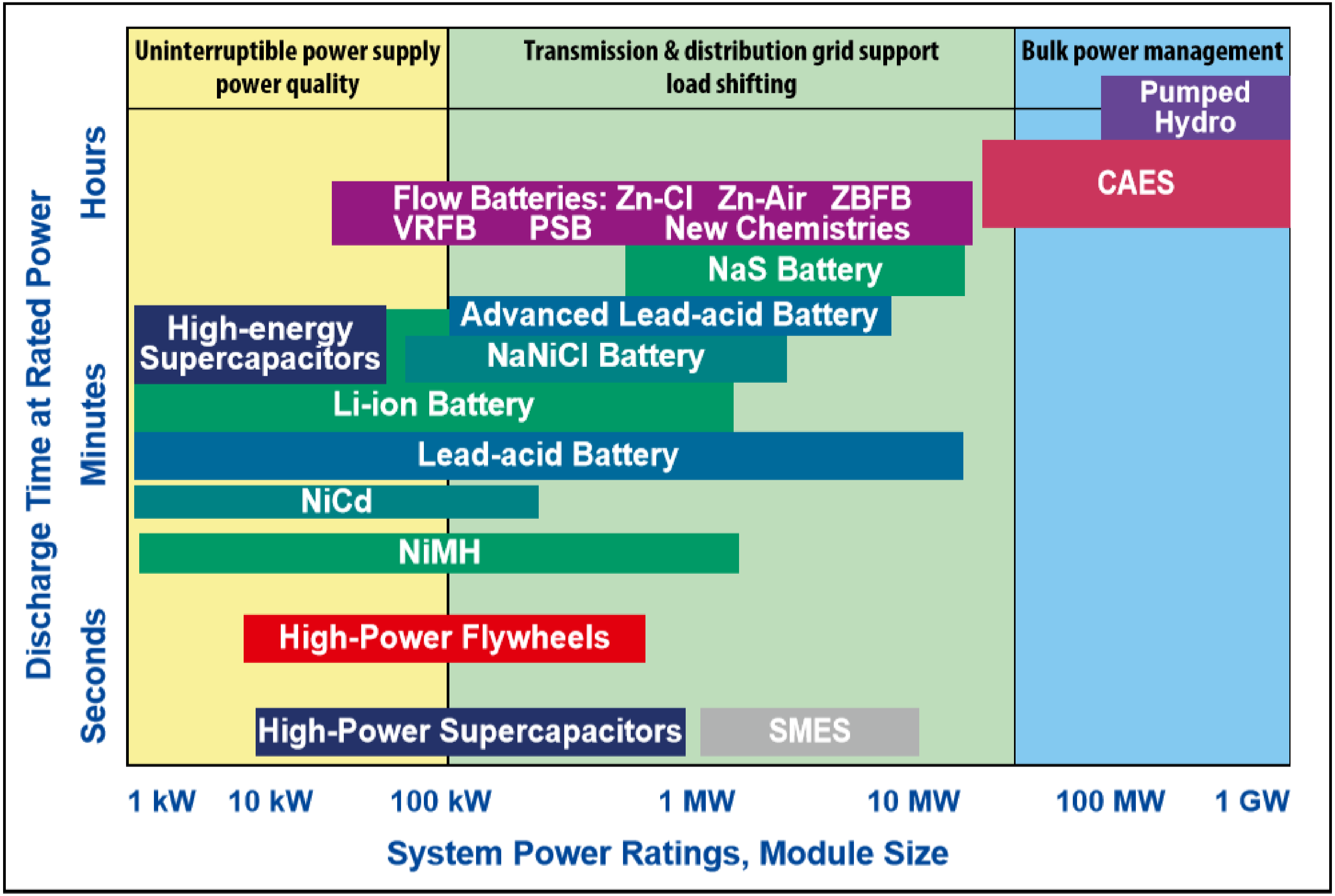


Source: Arabkoohsar, A., and H. Namib, Pumped hydropower storage, in*: Mechanical Energy Storage Technologies*, Chapter 4, 73-100, doi:10.1016/B978-0-12-820023-0.00004-3, 2021.

Other types of mechanical energy storage (MES) systems

- **Thermal energy storage** (TES) techniques, where thermal energy (either heat or cold) is stored via the use of a storage medium; classified into short-term and long-term systems.
- **Compressed air energy storage** (CAES) system, where the surplus electricity is used to produce compressed air at high pressures, while for producing extra power, the stored compressed air is used to drive air expanders and thereby actuate an electricity generator. Most appropriate for large-scale use and longer storage applications.
- **Flywheel energy storage** (FES), where the surplus electricity is stored in a high rotational velocity disk-shaped flywheel. The stored energy in the form of kinetic energy will be later used to drive a generator and thereby produce electrical power. Most appropriate for small- and medium-scale uses and shorter period applications.
- **Pumped thermal energy storage** (PTES) system, also known as pump heat energy storage, suitable for electricity storage at large- and medium-scale applications. Promising technology that is likely to be broadly implemented worldwide in the near future. This system can be used not only for electricity storage/production but also for cogeneration of electricity and heat or even trigeneration of electricity, heat, and cold.
- **Novel MES technologies** include: subcooled compressed air energy storage (SCAES), which is also known as trigeneration compressed air energy storage (TCAES); high-temperature heat and power storage (HTHPS), which comes in the two forms of air-based and steam-based; and gravity energy storage (GES), which comes in a variety of designs.

Comparison of EES technologies (1)



Πηγή: https://atlascorps.org/electricity-storage-renewables-costs-markets-2030/

Comparison of EES technologies (2)

	supercap	SMES	flywheel	lead-acid	lithium-ion	NaS	redox-flow	hydrogen	pumped hydro	CAES
energy density in Wh/l	2-10	0,5-10	**80-200**	50-100	**200-350**	**150-250**	20-70	**750/250bar 2400/liquid**	0,27-1,5	3-6
installation costs in €/kW	**150-200**	high	300	**150-200**	**150-200**	**150-200**	1000-1500	1500-2000	500-1000	700-1000
installation costs in €/kWh	10000-20000	high	1000	**100-250**	300-800	500-700	300-500	**0,3-0,6**	**5-20**	**40-80**
reaction time	**<10ms**	**1-10ms**	**>10ms**	**3-5ms**	**3-5ms**	**3-5ms**	>1s	10min	>3min	3-10min
self-discharge rate	up to 25% in first 48h	10-15 %/day	5-15 %/h	0,1-0,4 %/day	**5 %/month**	10 %/day	0,1-0,4 %/day	**0,003-0,03 %/day**	**0,005-0,02 %/day**	0,5-1 %/day
cycle life-time	**>1Mill.**	**>1Mill.**	**>1Mill.**	500-2000	**2000-7000**	**5000-10000**	**>10000**	>5000		
life-time in years	15	20	15	5-15	5-20	15-20	10-15	20	**80**	ca. 25
system efficiency in %	77-83	**80-90**	**80-95**	70-75	**80-85**	68-75	70-80	34-40	75-82	60-70
short-term (<1min)	**XXX**	**XXX**	**XXX**		x		x			
mid-term (>1min,<2d)			x	**XXX**	**XXX**	**XX**	**XX**	x	**XX**	**XX**
long-term (>2d)				x		x	**XX**	**XXX**	**XXX**	**XX**

Πηγή: Bocklisch, T., Hybrid energy storage systems for renewable energy applications, *Energy Procedia*, 73, 103-111, 2015