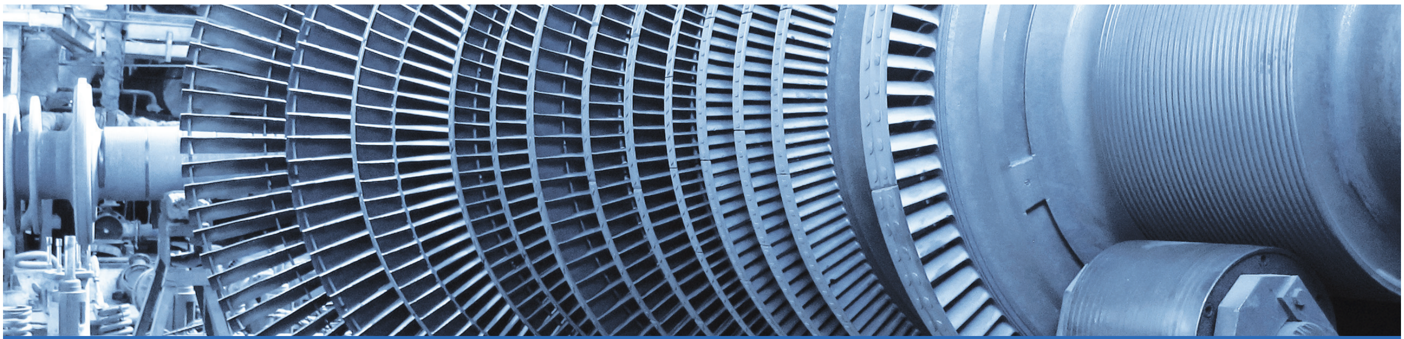
Pumped Heat Electrical Storage



Mechanical Energy Storage

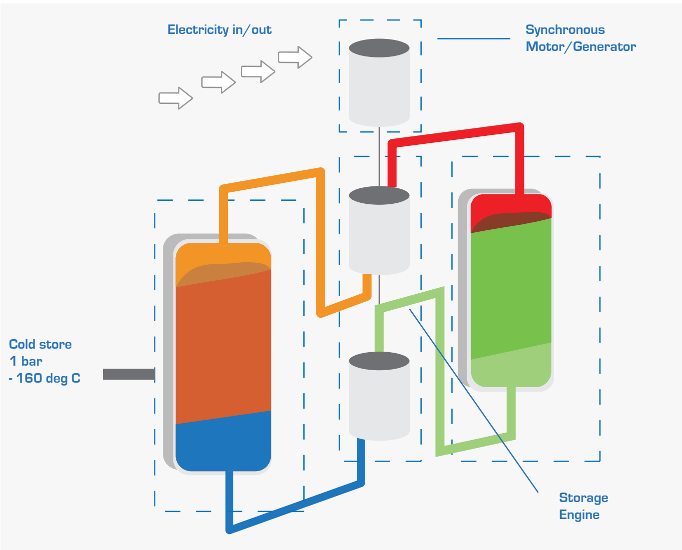
1. Technical description

A. Physical principles

Pumped Heat Electrical Storage (PHES) is analogous to pumped hydro storage but rather than pumping water uphill, heat is pumped from one thermal store (-160°C) to another (+500°C) using a reversible heat pump/heat engine (see illustration PHES). Reversing the process drives the heat engine and generates electricity. The heat storage material is crushed rock.

A closed circuit filled with the working gas connects the two stores, the compressor and the expander. A monatomic gas such as argon is ideal as the working gas as it heats up and cools down much more than air for the same pressure increase/decrease.

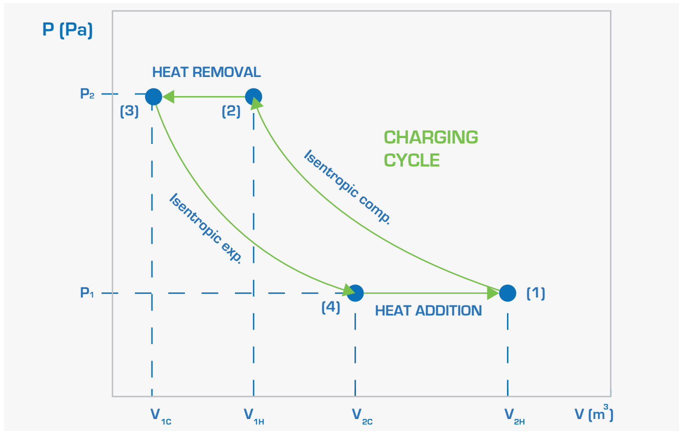
Illustration: PHES



Source : Isentropic

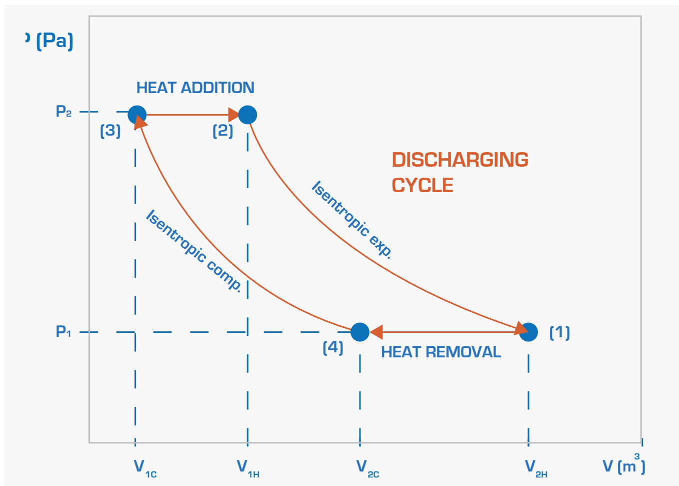
Charging – The argon, at ambient pressure and temperature (1), enters the compressor. The compressor is driven by a motor/generator using the electricity which needs to be stored. The argon is compressed to 12 bar, +500 °C (2). It enters the top of the hot storage vessel and flows slowly (0.5m/s) through the particulate, heating the particulate and itself cooling. As the particulate heats up, a hot front moves down the tank. At the bottom of the tank the argon exits, still at nearly 12 bar but now at ambient temperature (3). It then enters the expander and is expanded back to ambient pressure, cooling to -160 °C (4). The argon then enters the bottom of the cold vessel and flows slowly up, cooling the particulate and itself being warmed. It leaves the top of the tank back at ambient pressure and temperature (1).

Illustration: Charging Cycle



Discharging – To recover the power, the gas flow is simply reversed. Argon at ambient temperature and pressure enters the cold tank (1) and flows slowly down through it, warming the particulate and therefore becoming cold. It leaves the bottom of the tank at -160 °C (4) and enters the compressor. It is compressed to 12 bar, heating back up to ambient temperature (3). It then enters the bottom of the hot tank. It flows up, cooling the particulate and warming to +500 °C (2). The hot pressurized gas then enters the expander where it gives up its energy, producing work which drives the motor/generator to return to (1).

Illustration: Discharging Cycle



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B. Important components

The main components are the following:

- 2 low-cost containers filled with mineral particles
  (such as crushed rock or ceramic) – the thermal stores
- One or both of the thermal stores may be pressurised (up to 12 bar)
- A heat pump for charging
  A heat engine for discharging
  Ideally these may be the same machines
- The working fluid, Argon gas, which makes up 1% of the atmosphere
- One or more heat exchangers to reject waste heat

C. Key performance data

Power range	100 kW - 200 MW
Energy range	500kWh – 1000MWh
Discharge time	3-6 h
Cycle life	15000 cycles+
Life duration	20 - 30 years
Reaction time	1-2 seconds for reciprocating machines
Efficiency	70 - 75 %
Energy (power) density	15-30kWh/ton
CAPEX: energy	20 €/kWh
CAPEX: power	350 €/kW

D. Design variants (non exhausitive)

PHES simply scales with the needs of the grid – the capacity of the heat pump and that of the stores can be increased or decreased as required. Two main approaches:

- Use of purpose built machinery (Isentropic)
- Use of turbo machinery (Saipem)

2. State of the art

The PHES Technology is in development stage: Isentropic, Saipem,... In particular, Isentropic (UK), has received £14m funding to develop and build a 1.5MW system on a UK substation.

3. Future developments

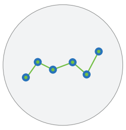
- Feasibility of high-efficiency turbo machinery suitable for operation in argon (different designs to air based turbo machinery) and at high temperatures. This is particularly relevant for the compression stage.
- Proving long life duration of PHES systems undergoing frequent stops and starts.
- Materials which can provide further improvements in cost per unit power and per unit capacity.

4. Relevance in Europe

As renewables penetration in European power grids increases, particularly as a result of such challenges as the decommissioning of nuclear reactors in Germany, PHES can provide peak levelling and grid stability. Since none of its components are hazardous, it will also be a safe solution, both in operation and in decommissioning.

5. Applications

The PHES systems can be connected at the transmission or distribution level and can provide the following services:



Arbitrage

Secondary, tertiary reserveand voltage regulation

6. Sources of information

- EASE members
- RWTH Aachen
- ENEA Consulting
- Isentropic
- ARUP
- Saipem