Power-to-Heat Integration in Solid Media Thermal Energy Storage: Increasing System Cost Efficiency and Flexibility

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Utility-scale Electrical Energy Storage (EES) supports the expanding integration of intermittent renewable energy sources allowing a reliable and flexible supply of low-carbon or even zero-carbon electricity. Emerging EES technologies introduced in Fig. 1 are considered adiabatic due to the implementation of thermal energy storage (TES) following the adiabatic compression and prior to the adiabatic expansion. Based on the Carnot heat pump cycle during charging and, when operating in reverse as a Carnot heat engine during discharging period, this EES technologies are considered as Carnot energy storage, since their operation occur with a theoretical round-trip efficiency of 100%. However, capital costs of these adiabatic concepts are still too high for an economical operation in future electricity transmission systems.

Large-scale conversion of electricity into thermal energy in a high-temperature heat pump cycle with subsequent conservation inside TES increases the energy density of the overall process. Such process hybridization through the integration of Power-to-Heat (PtH) towards a partial adiabatic operation management decreases the round-trip efficiency on the one hand, but, opens up the potential for improvements in flexibility as well as cost efficiency on the other hand. Results from wide-range simulation studies of an exemplary ACAES configuration indicate in Fig. 2 a significant decrease of specific capital costs for increased integration of electrical heating capacity through PtH, however, the total efficiency is decreasing due to the partial adiabatic operation. The present contribution aims at introducing a dimensionless modelling approach for development of suitable design solutions for the electrical heating component in combination with solid media thermal energy storage. Based on this thermodynamic model, results for energy- and cost-efficient ETES configurations with higher process flexibility are identified.

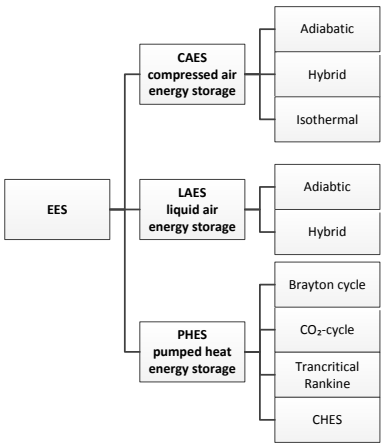

Fig. 1: EES technologies and related process classification

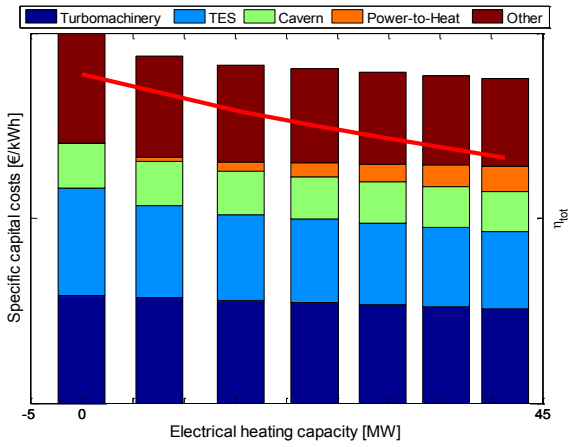

Fig. 2: Specific capital costs and total efficiency of an exemplary ACAES concept related to electrical heating capacity