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Multicriteria optimization of Brayton-like pumped thermal electricity storage with liquid media

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ABSTRACT

A multi-objective and multi-parametric optimization of a Pumped Thermal Electricity Storage system based on Brayton cycles is presented by the calculation of different Pareto fronts and the associated Pareto optimal sets for energetic and design analysis, respectively. A large range of internal and external irreversibilities and the thermodynamic properties of the storage media are taken into account. The analysis shows that the heat capacity of the working fluid and the heat capacity of the storage media should be the same in the contact with the hot reservoirs and in the contact with the cold reservoir in the heat pump, but in the contact with the cold reservoir for the heat engine the ratio should be 0.33, this offers information regarding the mass flow increasing significantly the achievable values for the round-trip efficiency, power output and the heat engine efficiency in the discharge process. Optimal values are given in terms of the degree of irreversibilities in the system and a comparison is made with extreme cases of infinite and minimum sizes for the storage system. Round-trip efficiencies in the so-called optimum scale/mass-flow-ratio design point exhibits noticeably larger values compared to previously reported results including the so-called endoreversible limit, where no internal irreversibilities are considered and where the improvement can achieve 49% over the endoreversible case in the most ideal scenario. Explicit numerical values of the maximum round trip efficiency, power output, and efficiency are given for a broad range of both internal and external irreversibilities.

1. Introduction

Electric energy storage technology based on the joint use of a heat pump and a heat engine cycles (pumped thermal electricity storage, PTES) is nowadays a real alternative to most conventional technologies as compressed air energy storage (CAES) or pumped hydro storage (PHS) [1]. It does not require neither underground caves nor high-sized reservoirs and then, it is not dependent on geographic or geological conditions [2]. In PTES devices energy is stored in the form of heat in a hot tank with manageable dimensions using a heat pump (HP)-cycle which extracts heat from a lower temperature tank containing a cryogenic liquid [3]. Later-on, the energy stored (in molted salts [4], for example) is converted into electric energy in a discharge process through a heat engine (HE) cycle working between the same thermal energy storage (TES) media [5].

Compared with solid media storage [6], two clear additional advantages of the liquid storage are: (a) the pressure inside the tanks is independent of the pressure of the cyclic working fluid (opposite to what happens in packed bed storage systems) and then, more compact heat exchangers can be used; and (b) the temperature inside each tank remains almost constant, avoiding the problems associated to the propagation of the hot front in solid storage [7,8]. The drawback is the need for two tanks for each reservoir with specific technical requirements [9] (high volumetric specific energy, high heat rate with the working fluid, high thermal stability, flexibility for implementation, storage capacity for hours of operation, and long lifetime). For the cryogenic fluids [10] and the storage salts [11], lower and upper limits in the temperature should be taken into account [12] in order to ensure stable liquid phases under the whole cyclic working fluid temperature variations [13] .

PTES layouts [14], even those with de-coupled thermal stores [15] and unbalanced mass flow rate [16], mostly uses a single-phase working fluid operating a Brayton-like [17] cycle or Rankine-like cycle [18] with CO_2 as working fluid [19]. Most of full theoretical studies are

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