entropy

Article

Thermodynamic Performance of a Brayton Pumped Heat Energy Storage System: Influence of Internal and External Irreversibilities

David Pérez-Gallego [1], Julian Gonzalez-Ayala [1,2,*], Antonio Calvo Hernández [1,2] and Alejandro Medina [1,2]

[1] Departamento de Física Aplicada, Universidad de Salamanca, 37008 Salamanca, Spain; id00698231@usal.es (D.P.-G.); anca@usal.es (A.C.H.); amd385@usal.es (A.M.)
[2] Instituto Universitario de Física Fundamental y Matemáticas (IUFFyM), Universidad de Salamanca, 37008 Salamanca, Spain
* Correspondence: jgonzalezayala@usal.es

Abstract: A model for a pumped thermal energy storage system is presented. It is based on a Brayton cycle working successively as a heat pump and a heat engine. All the main irreversibility sources expected in real plants are considered: external losses arising from the heat transfer between the working fluid and the thermal reservoirs, internal losses coming from pressure decays, and losses in the turbomachinery. Temperatures considered for the numerical analysis are adequate for solid thermal reservoirs, such as a packed bed. Special emphasis is paid to the combination of parameters and variables that lead to physically acceptable configurations. Maximum values of efficiencies, including round-trip efficiency, are obtained and analyzed, and optimal design intervals are provided. Round-trip efficiencies of around 0.4, or even larger, are predicted. The analysis indicates that the physical region, where the coupled system can operate, strongly depends on the irreversibility parameters. In this way, maximum values of power output, efficiency, round-trip efficiency, and pumped heat might lay outside the physical region. In that case, the upper values are considered. The sensitivity analysis of these maxima shows that changes in the expander/turbine and the efficiencies of the compressors affect the most with respect to a selected design point. In the case of the expander, these drops are mostly due to a decrease in the area of the physical operation region.

Keywords: energy storage; round-trip efficiency; irreversibilities; Brayton cycle; heat pump

Citation: Pérez-Gallego, D.; Gonzalez-Ayala, J.; Calvo Hernández, A.; Medina, A. Thermodynamic Performance of a Brayton Pumped Heat Energy Storage System: Influence of Internal and External Irreversibilities. *Entropy* **2021**, *23*, 1564. https://doi.org/10.3390/e23121564

Academic Editors: Miguel Rubi and Armin Feldhoff

Received: 22 October 2021
Accepted: 19 November 2021
Published: 24 November 2021

1. Introduction

Increasing production of electric energy from renewable sources like wind or Sun makes essential energy storage technologies due to the inherent intermittency of such natural resources [1]. Substantial efforts are being devoted to the so-called Pumped Thermal Energy Storage (PTES) systems [2]. They are aimed at storing energy during the hours with an excess of, for instance, wind or photovoltaic production. When electric energy is subsequently required, heat is transformed again in electricity through some thermodynamic cycle. Required storage periods could be not very long, from four to eight hours. At grid-scale, the only proven competitors of this concept are Pumped Hydro Energy Storage and Compressed Air Energy Storage [3]. Nevertheless, these technologies require very particular geographical and geological scenarios that make difficult their implementation where required [4]. On the other hand, electric batteries, as with lithium ones, are still very expensive at grid-scale.

Recently, Dumont et al. [5] have proposed the term *Carnot batteries* to those systems that are used to store energy by establishing a temperature difference between two media (low and high temperature reservoirs). In the charge period, energy is stored (usually by means of a thermal heat pump). And after a storage period, electric energy is produced by a heat engine that works between those reservoirs. Several configurations and thermodynamic