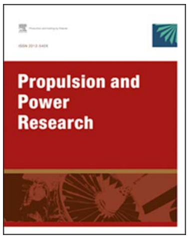
HOSTED BY
ELSEVIER

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com



ORIGINAL ARTICLE

Q1 Lowering the cost of large-scale energy storage: High temperature adiabatic compressed air Q2 energy storage

B. Cárdenas[a,*], **A.J. Pimm**[b], **B. Kantharaj**[a], **M.C. Simpson**[a], **J.A. Garvey**[c], **S.D. Garvey**[a]

[a]*Department of Mechanical, Materials and Manufacturing Engineering Faculty of Engineering, University of Nottingham, Nottingham NG7 2RD, United Kingdom*
[b]*Centre for Integrated Energy Research, School of Chemical and Process Engineering, University of Leeds, Leeds LS2 9DT, United Kingdom*
[c]*School of Mechanical Engineering, University of Leeds, Leeds LS2 9DT, United Kingdom*

Received 15 November 2016; accepted 10 March 2017

KEYWORDS

High temperature compressed air energy storage (CAES);
Preheating of air;
Generation integrated energy storage;
Electric grid balancing;
Electricity storage;
Renewable generation intermittence

Q3 **Abstract** Compressed air energy storage is an energy storage technology with strong potential to play a significant role in balancing energy on transmission networks, owing to its use of mature technologies and low cost per unit of storage capacity. Adiabatic compressed air energy storage (A-CAES) systems typically compress air from ambient temperature in the charge phase and expand the air back to ambient temperature in the discharge phase. This papers explores the use of an innovative operating scheme for an A-CAES system aimed at lowering the total cost of the system for a given exergy storage capacity. The configuration proposed considers preheating of the air before compression which increases the fraction of the total exergy that is stored in the form of high-grade heat in comparison to existing designs in which the main exergy storage medium is the compressed air itself. Storing a high fraction of the total exergy as heat allows reducing the capacity of costly pressure stores in the system and replacing it with cheaper thermal energy stores. Additionally, a configuration that integrates a system based on the aforementioned concept with solar thermal power or low-medium grade waste heat is introduced and thoroughly discussed.

© 2017 National Laboratory for Aeronautics and Astronautics. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

---

[*] Corresponding author. Tel.: +44 (0) 115 951 3811.

E-mail address: Bruno.Cardenas@nottingham.ac.uk (B. Cárdenas).

Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

http://dx.doi.org/10.1016/j.jppr.2017.06.001

2212-540X © 2017 National Laboratory for Aeronautics and Astronautics. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Please cite this article as: B. Cárdenas, et al., Lowering the cost of large-scale energy storage: High temperature adiabatic compressed air energy storage, Propulsion and Power Research (2017), http://dx.doi.org/10.1016/j.jppr.2017.06.001

UNCORRECTED PROOF

Nomenclature

c	specific heat capacity (unit: J/(kg · K))
$\dot{m}$	mass flow rate of air (unit: kg/s)
n	number of stages of compression/expansion in the system
P	pressure (unit: Pa)
R	specific gas constant for air (unit: J/(kg · K))
s	specific entropy (unit: J/(kg · K))
T	temperature (unit: K)
u	specific internal energy (unit: J/kg)
W	work done by the compressors (unit: W)
X	fraction of the total exergy that is stored as high grade heat

Greek letters

γ	ratio of specific heat capacities
σ	compression ratio per stage
ψ	exergy content per unit mass (unit: J/kg)

Subscripts

0	ambient conditions
1–9	reference to a certain state within the system
H.G.TES	reference to the high grade thermal energy store
high	maximum level of variable within the system
L.G.TES	reference to the low grade thermal energy store
med	intermediate level of variable within the system
p	isobaric
v	isochoric

1. Introduction

At present there is a growing impetus worldwide towards replacing traditional fossil-fuelled power generation with clean energy sources in view of the serious environmental threats posed by the emission of greenhouse gases. However, as the electric network is decarbonized, the challenge of matching supply to demand intensifies because renewables and nuclear are much less flexible than fossil fuels due to their intermittent and not entirely predictable nature and high thermal inertia, respectively [1,2].

Therefore, having effective energy storage methods by means of which the disparity between energy availability and consumption can be managed is imperative to achieve a much more widespread utilization of inflexible renewable generation [3]. Compressed air energy storage (CAES) has been extensively studied and is regarded as a competitive and very promising utility-scale solution for providing stability and other ancillary services to the electric grid [4].

The operation of a CAES system can be divided into two phases: a charge (storage) phase which occurs during off-peak periods and a discharge (generation) phase which occurs during periods of high-demand. When operating in the charge phase a CAES system utilizes electrical energy from the grid to compress air, which is stored at a high pressure and near ambient temperature in a reservoir that may be an underground cavern or a pressure vessel placed aboveground or underwater. Hence, it may be stated that CAES systems store excess electricity in the form of mechanical potential of the pressurized air. During the discharge phase, the compressed air is extracted from the reservoir, heated and expanded in a turbogenerator to deliver electricity to the grid.

Currently there are only two operational large-scale CAES plants, one is located in Huntorf, Germany and the other one is found in McIntosh, Alabama. These CAES plants, known as diabatic or conventional CAES, produce pressurized air through a multi-stage compression process. The heat resultant from each compression stage is removed from the air stream and rejected to the atmosphere. Finally, the cool compressed air is stored in a solution mined underground salt cavern. When operating in discharge mode, the compressed air is released from the reservoir and used as the combustion air in gas turbines to produce work. Before being expanded, the air is heated in combustion chambers to increase the work output and prevent any moisture content from freezing in the turbines [5].

The main drawback of these plants is that energy is vented to atmosphere (in the form of heat) in the charging phase, and an additional energy input (combusted natural gas) is used to regenerate the electric energy that was stored, markedly affecting their roundtrip efficiency.

An improved configuration known as adiabatic CAES (A-CAES) has been investigated by many researchers [6–11]. These systems operate very similarly to the existing plants, the main difference being the integration of heat storage. During the charge phase, the heat of compression is removed from the compressed air stream and stored in dedicated thermal energy stores (TES) instead of being vented to atmosphere. Subsequently, during the discharge phase this heat is restored to the air to increase its temperature before expansion, eliminating the need to burn gas and thus giving A-CAES systems a higher efficiency than diabatic CAES systems and the benefit of being a storage technology with zero combustion emissions. It has been reported that A-CAES systems have the potential of reaching round-trip efficiencies of up to 70% [12,13].

The pressure vessel of a CAES system has in many cases a higher cost than heat storage materials per unit of exergy storage capacity. A study carried out by Black & Veatch in 2012 revealed that for a 260 MW system with 15 h of storage the cost of the cavern (pressure store) represented 40% of the total capital cost of the A-CAES system [14]. It is therefore logical to try to maximize the amount of exergy stored by an A-CAES system in the form of heat.

UNCORRECTED PROOF

Please cite this article as: B. Cárdenas, et al., Lowering the cost of large-scale energy storage: High temperature adiabatic compressed air energy storage, Propulsion and Power Research (2017), http://dx.doi.org/10.1016/j.jppr.2017.06.001

Download English Version:

https://daneshyari.com/en/article/8059152

Download Persian Version:

https://daneshyari.com/article/8059152

Daneshyari.com