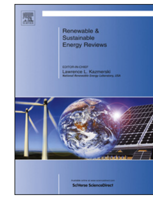
Renewable and Sustainable Energy Reviews 29 (2014) 865–882

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Comparison of the performance of compressed-air and hydrogen energy storage systems: Karpathos island case study

S. Karellas*, N. Tzouganatos

National Technical University of Athens, Laboratory of Steam Boilers and Thermal Plants, School of Mechanical Engineering, 9 Heroon Polytechniou, 15780 Zografou, Athens, Greece

ARTICLE INFO

Article history:
Received 6 December 2011
Received in revised form
9 July 2013
Accepted 14 July 2013
Available online 2 October 2013

Keywords:
Compressed air energy storage (CAES)
Hydrogen storage
Performance evaluation
Karpathos island

ABSTRACT

Two diverse energy storage technologies, namely the compressed-air and hydrogen energy storage systems, are examined. In particular, a steady state analysis (IPSEpro simulation software) of four configurations of micro-CAES systems is conducted from the energetic and exergetic point of view. The hydrogen energy storage system is dynamically simulated using the HOMER energy software. Load and wind profiles for the island of Karpathos are used as input data to the program. The two-stage micro-CAES system without air preheating is selected to be investigated dynamically as it is proven to have high efficiency and zero emissions. The last part of the paper compares the two systems in terms of energy storage efficiency, includes an approximation of the costs and highlights the technological advantages and disadvantages of these technologies.

Contents

* Corresponding author. Tel.: +30 210 7722720; fax: +30 210 7723663.
E-mail address: sotokar@mail.ntua.gr (S. Karellas)

1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.07.019

1. Introduction

The increasing world energy demand along with the predicted abrupt escalation in oil prices and the need to curb greenhouse gas emissions resulted in a remarkable growth of electricity generated from renewable energy sources (RES). However, the introduction of these fluctuating energy sources brings about important network stability problems due to a supply–demand imbalance and makes the need for energy storage more demanding than ever before. And this problem is getting worse when it comes to decentralized electricity production.

As far as Greece is concerned, the problem consists of two major components: (a) the presence of many islands with no electricity transfer possibilities and (b) the abrupt increase of the electrical load during the high season. Specifically, as RES fluctuate independently from electricity demand, there will be times when the unmet load should be met by a conventional plant. As a result, and in order to satisfy 100% of the electricity needed through RES, energy storage is required [1]. Development of storage methods will open up a new field of application, especially due to the growth of electrical production from renewable energy, along with decentralized production.

Aim of this work is the investigation – from the steady-state and dynamic point of view – and comparison of two energy storage methods: energy storage by means of compressed air and hydrogen (H_2), which are applied in a community of the Greek island Karpathos.

2. Compressed air energy storage (CAES)

Compressed air energy storage is a promising method of energy storage due to its high efficiency and the fact that it relies on mature technology with several projects in place. Currently, there are two conventional CAES plants operating (Neuenhuntorf [2] and McIntosh), while two more plants are under construction (Norton and Iowa [3]) [4–7]). As far as AA-CAES plants (adiabatic compressed air storage systems) are concerned, industrial applications are expected approximately in 2015. The construction of the pilot project of EnBW AG is expected to be completed in 2013, but at the first stage it will be operated as a conventional air storage plant and at the second stage as an AA-CAES with overall efficiency of about 70% and capacity ranging from 150 to 600 MW [4].

2.1. Conventional CAES

The operation of a conventional compressed air energy storage system is described as follows: excess electricity during off-peak hours is used to drive a 2-stage compressor with intercooling. After the compression, the compressed air (40–70 bar) is led to an after-cooler before it gets stored in an underground storage reservoir. At peak hours, a combustion chamber is employed in order to heat-up stored air and, as a result, to obtain increased power during the expansion process (expansion with reheating). The operating principle of the Neuenhuntorf CAES plant [7] is presented in Fig. 1.

In modern systems, a recuperator is also used in order to preheat the stored compressed air before it enters the combustion chamber. This way, the efficiency of the system is increased by 10%. However, a significant drawback of this configuration is the big size of the recuperator, which implies an increase in the investment costs of the plant [1]. The CAES plants at McIntosh and Neuenhuntorf represent the two options of operating a conventional power plant (with and without the use of a recuperator respectively) [7]. The operating principles of the McIntosh plant are presented in Fig. 2.

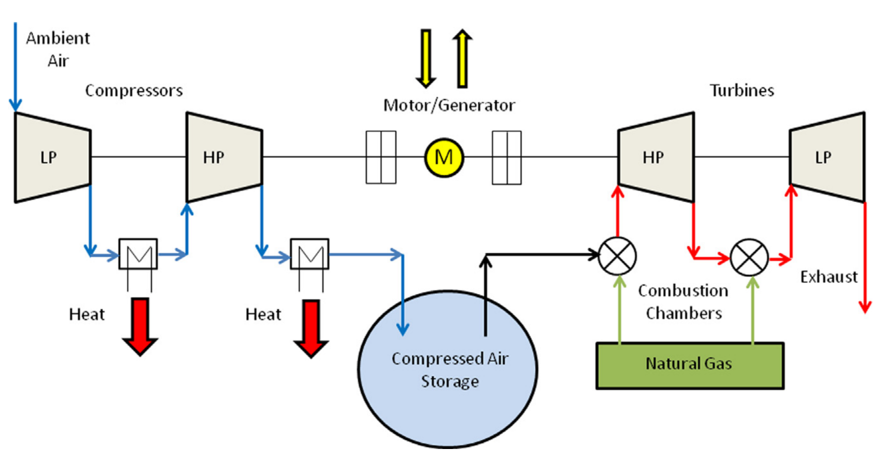


Fig. 1. Operating principle of the CAES plant Neuenhuntorf.