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Performance study of an advanced adiabatic compressed air energy storage system

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Abstract

Renewable energy sources such as wind and solar, have vast potential to offer cost competitive power supply and reduce dependence on fossil fuels and environmental issues in the electric sector. However, renewable energy systems often have variable and uncertain energy supply which makes electrical energy storage systems highly valuable for renewable energy applications. Compressed air energy storage is one of the most promising technologies that have received wide attention in scientific community. In this paper, a comprehensive thermodynamic model is developed to investigate the thermal performance of an Advanced Adiabatic Compressed Air Energy Storage (AA-CAES) system. The effect of key parameters including storage pressure, pre-set pressure along with compressor and turbine efficiencies on the system performance is studied. The results show that the storage pressure has a significant effect on the amount of energy stored in the AA-CAES and power generated by the expander. As the storage pressure increases from 2 MPa to 10 MPa, the amount of energy stored increases from 7.8 MJ/m^3 to 105.6 MJ/m^3 while the output power increases from 4.2 to 63.2 MJ/m^3. The results also show that the overall energy conversion efficiency is dominated by the efficiency of the compressor and turbine. As the efficiencies of both compressor and expander increases from 0.65 to 0.95, the efficiency of the AA-CAES system is improved from 35% to 74%. This study provides a deep understanding of operation characteristics of the AA-CAES system and useful information for system design and optimization.

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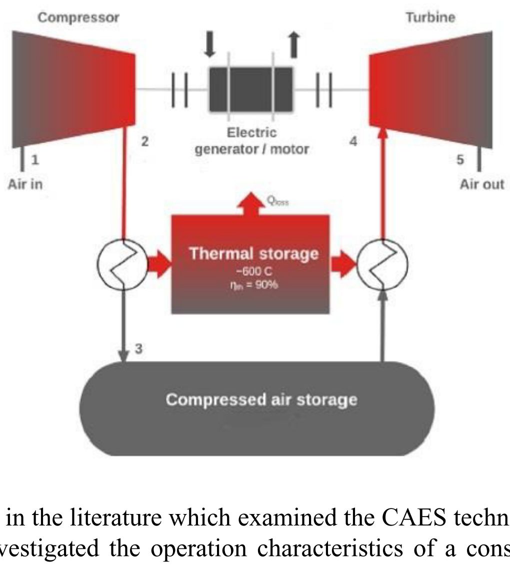
1. Introduction

Due to energy crisis and environment issues such as air pollution and global warming caused by combustion of fossil fuels, the use of alternative sources especially renewable energies has attracted an increasing attention in many countries [1]. However, the main drawback of renewable sources, such as wind energy, solar energy, bio-energy and etc., is their intermittence, randomness and volatility making their development a huge challenge confronted. As a result, in order to effectively utilize these renewable energy sources, it is important to find a way for resolving these drawbacks [2]. There is a variety of possibilities introduced to employ the volatile renewable energy sources [3] among which the energy storage technology is considered as one of the most promising methods. This technology can be divided in two categories of the physical storage, such as flywheel energy storage, compressed air storage and pumped hydro energy storage, and the electrochemical energy storage such as, batteries, fuel cells and electrolytic hydrogen [4].

Amongst all different types of energy storage approaches, the compressed air energy storage (CAES) system offers many competitive features such as large power and energy capacity, high cycle lifespan, and fast response time. These features make CAES systems particularly suitable for energy storage purposes in the electric grid [5]. In a typical CAES, the air is compressed by a compressor using off-peak, cheap electricity or the excess energy of renewable energy sources, such as a wind turbine or solar energy. Before transferring to the storage vessel, the compressed air is cooled to the near ambient temperature to ensure high compression efficiency and maximum storage utilization. This pressurized air is released into a gas turbine to generate electricity when it is on demand in peak hours or for other grid balancing and regulation purposes [6-7]. In recent years, the Advanced Adiabatic compressed air energy storage system (AA-CAES) was proposed to increase the efficiency by improving the cooling procedure of the compressed air. In such systems, a thermal storage made of a fluid or solid is added to store the compression heat for later use during expansion. In other words, by employing a thermal storage, it saves fossil fuels for reheating the air before expansion in the gas turbine. Consequently, AA-CAES systems have shown the potential for higher efficiencies and less greenhouse gasses emissions. A schematic drawing of an AA-CAES system is shown in Fig. 1.

Fig.1. A schematic of an AA-CAES system



There are many studies available in the literature which examined the CAES technology. Kim et al. [8] applied an exergy and energy analysis and investigated the operation characteristics of a constant-pressure CAES system in different compression and expansion processes. In this research, instead of elevation difference of the water column previously proposed in literature [9], a hydraulic pump was designed to provide the CAES with constant air pressure. Grazzini and Milazzo [10-11] developed a thermodynamic analysis for a multistage adiabatic compressed air energy