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Overview of current development in compressed air energy storage technology

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Abstract

With the rapid growth in electricity demand, it has been recognized that Electrical Energy Storage (EES) can bring numerous benefits to power system operation and energy management. Alongside Pumped Hydroelectric Storage (PHS), Compressed Air Energy Storage (CAES) is one of the commercialized EES technologies in large-scale available. Furthermore, the new advances in adiabatic CAES integrated with renewable energy power generation can provide a promising approach to achieving low-carbon targets. The small-scale CAES facilities are also attracting attention for more flexible power system applications. This paper will present an overview of different types of multi-scale CAES, including their working principles, current development, typical technical and economic characteristics, existing facilities, application potentials, challenges and issues associated with the future development of CAES.

Keywords: compressed air energy storage, overview; large and small scale; application area; technical and economic characteristics.

1. Introduction

Electrical Energy Storage (EES) has long been considered as crucial mechanism for ensuring power system operation stability and reliability. In particular, it has recently attracted more attentions due to the rapidly increasing renewable power generation. Pumped Hydroelectric Storage (PHS) is an EES technology with high technical maturity and large energy capacity. With an installed capacity of 127-129 GW in 2012, PHS represents around 99% worldwide bulk storage capacity [1, 2, 3]. In addition to PHS, CAES is another type of commercialized EES technology, which can provide above 100 MW of power output via a single unit as well as having bulk energy storage capacity [4]. CAES operates in the way of storing energy in the form of high pressure compressed air during the periods of low electrical energy demand and then releasing the stored compressed air energy to generate electricity to meet high demand during the peak time periods. CAES can be built to have the scales from small to large and the storage durations from short to long with moderate response time and good part-load performance in comparison

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with other EES technologies. A CAES installation refers to a system which integrates different interacting components, devices and processes, such as compressors, turbines/ expanders and electrical machines. CAES can combine with alternative EES technologies to achieve the required energy capacity, energy density, response time or efficiency.

Nowadays, different types of CAES technologies have been commercialized or are under development. This can make the difficulty to evaluate the current state of this important EES technology. The paper aims to provide an updated picture of the status of CAES technology to support the relevant R&D in both academia and industry. It starts with the introduction of working principles of different types of CAES, and then overviews the CAES technical and economic characteristics, commercialized facilities, the state-of-the-art, application potentials and challenges associated with the future development.

2. Working Principles of CAES

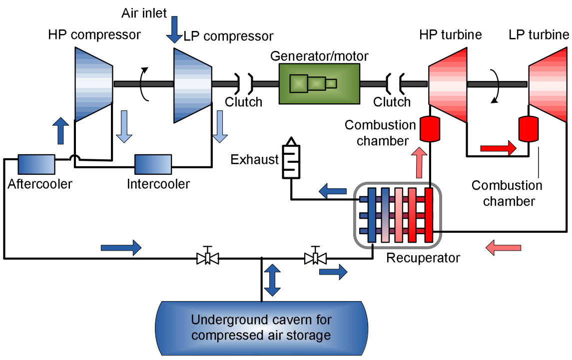

Fig.1 Schematic diagram of a conventional compressed air energy storage system

The working process of a traditional large-scale CAES plant is described as follows. During the compression mode the surplus electricity is used to run a chain of compressors to inject the air into a storage reservoir, normally an underground cavern for large-scale CAES. The compressed air is stored at a high pressure and at the temperature of the surrounding formation. Such a compression process can use coolers to reduce the working temperature of the injected air and thus to improve the compression efficiency (Fig. 1) [4]. During the expansion mode, the stored high pressure compressed air is released, heated, and then expanded through a group of turbines which includes gas turbine(s) and sometimes steam turbine(s) [4, 5, 6, 7]. The combustion process in the gas turbine with the mixed compressed air and fuel (typically natural gas) occurs in the combustion chamber of turbine(s). The turbines are connected to an electrical generator to generate electricity (Fig. 1). The waste heat of the overall system exhaust can be recycled before it is released into atmosphere [4, 5]. The main feature of conventional large-scale CAES plants is that it involves combusting fossil fuels via gas turbines, resulting in CO_2 emissions. Both the commercialized Huntorf (110 MW) and the McIntosh (290 MW) plants were implemented through the conventional CAES technology [4-6].

With the development of technology, several improvements and advanced concepts to large-scale CAES have been proposed. Among these concepts, the most promising CAES scheme is Advanced Adiabatic CAES (AA-CAES). When the AA-CAES system is operated at the expansion mode, by integrating a Thermal Energy Storage (TES) system, the energy stored in the compressed air is converted into the electrical power output without a combustion process involved (Fig. 2). Thus the significant benefit of AA-CAES systems is zero carbon emissions, assuming that the electricity for the compression mode is also from zero carbon energy sources. The processes of cooling airflow through compressors and