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Pressure response of large-scale compressed air energy storage in porous formations

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Abstract

Large-scale compressed air energy storage (CAES) in porous formations can contribute to compensate the strong daily fluctuations in renewable energy production. This work presents a hypothetical CAES scenario using a representative geological anticlinal structure in Northern Germany and performs numerical simulations to estimate pressure response in the storage formation. The results show that the induced pressure changes laterally throughout the storage formation are due to initial fill of the air storage. Because of high air compressibility, the pressure fluctuations caused by daily cyclic operation can only be observed in the gas phase which reaches a distance of roughly 500 m.

Keywords: Compressed air energy storage; porous formations; pressure response; numerical simulation

1. Introduction

With the rapid growth of energy production from intermittent renewable sources like wind and solar power plants, energy storage in geological formations has a large potential to compensate for fluctuating power generation on different time scales [1], such as subsurface storage of heat, subsurface hydrogen storage [2,3], and compressed air energy storage (CAES) [4–7]. Compared to other energy storages, CAES has been seen as a promising option for balancing short-term diurnal fluctuations, especially for wind farms [8]. CAES is a power-to-power energy storage [9],

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which converts electricity to mechanical energy, i.e. highly pressurized air, and stores it in the subsurface. During peak load, the pressurized air is used to generate electric power through gas turbines. Currently, only two CAES facilities in Huntorf in Germany and McIntosh in the US are operating and both use salt caverns as storage for the compressed air [10]. However, for a wide-spread use of CAES with storage caverns, the suitable salt deposits do not exist everywhere. Porous geological formations are more widely available and can offer even larger storage capacities for CAES. To investigate the use of geological porous formations for large-scale CAES, a reliable quantification of the possible induced hydraulic, thermal, chemical and mechanical impacts is required [11,12]. Therefore, in this study, we present a hypothetical large-scale CAES scenario using a representative geological anticlinal structure in Northern Germany, and perform numerical simulations to investigate the pressure response in the storage formation induced by initial fill of the gas reservoir and daily cyclic operation.

2. Scenario definition

A hypothetical conventional CAES facility is considered in this work, which only stores the mechanical energy of the compressed air, i.e. in the form of high pressure, and does not reclaim the heat from air compression [13]. The Huntorf power plant is the first conventional CAES facility and has almost 40 years successful operating experience. In this scenario, the gas turbine set-up of the Huntorf power plant is used, which requires an air mass flowrate of 417 kg/s with a minimum turbine inlet pressure of 43 bar to produce 321 MW electric power [4,10,14]. Instead of two salt caverns, a porous formation in an anticlinal structure is used as the storage reservoir (see Fig.1).

The chosen anticline (Fig. 2a) is synthetically generated based on the geometrical data of suitable anticline structures found in the tectonic atlas of Northern Germany [15]. The anticline top is assumed to be at a depth of 700 m, the drop to be 900 m, with a closure radius of roughly 4 km and thus a dip angle of roughly 16°. The storage formation in this anticline is a homogenous permeable 20 m-thick saline aquifer bounded by two 30 m-thick impermeable layers. The lateral extension of the anticline is about 16 km. Referring to the on-site data [16,17] and the statistical study [18] from the Rhaetian formation in Northern Germany, the storage formation is assumed to have an average permeability of 500 mD and a porosity of 0.35.

Due to the fast growth of power generation from photovoltaics, surplus energy is predicted as being highest at around noon [19]. Add-on power would thus be required in the morning and evening. A daily operational cycle (Fig. 2b) is thus assumed to produce power using the air storage for 6 hours in the morning (3 a.m. to 9 a.m.) and again in the afternoon (3 p.m. to 9 p.m.). Times of no production, i.e. around noon and midnight, are used to recharge the storage by using surplus electricity to inject the air. Both the injection and extraction air mass flow rate are set to 417 kg/s.

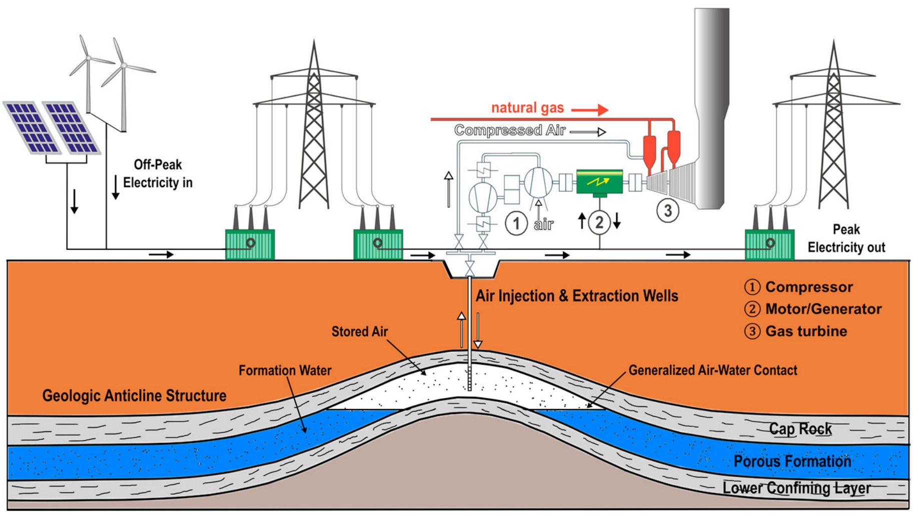

Fig. 1. A schematic sketch of a hypothetical conventional CAES facility using a porous formation as the storage reservoir [7].