Techno-economic modelling of large scale compressed air energy storage systems

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Abstract

Interest in integrating energy storage systems into the power grid has increased in Europe over the past decade due to strategies to overcome the intermittent nature of renewable electricity sources. One of these technologies is compressed air energy storage (CAES). The main purpose of this paper is to examine the technical and economic potential of CAES systems. In this work, two configurations a) Adiabatic Compressed Air Energy Storage (A-CAES); and b) Conventional Compressed Air Energy Storage (C-CAES) were modelled using the ECLIPSE suite of process simulation software. The nominal compression and power generation of both systems were given at 100MWe and 140MWe respectively. For each mode of operation an energy analysis was carried out. Energy use was calculated and compared for each system mode. Based on the results of mass and energy balances, an economic evaluation of the systems was conducted. Technical results showed that the overall efficiency of the A-CAES system would be 64.7%, considerably better than that of the C-CAES system at 52.6%. However it could be seen in the economic analysis that the breakeven electricity selling price (BESP) of the A-CAES system was 152€/MWh, much higher than that of the C-CAES system at 95€/MWh on average.

1. Introduction

Given the challenges of climate change, there must be new methods that will help people to reduce greenhouse gas (GHG) emissions caused by the combustion of fossil fuels. Obviously, big reductions in GHG emissions would be achieved by increasing the amount of electricity generated through renewable
energy technologies and relying less on coal and natural gas. Wind power, as one form of renewable energy has grown a great deal in the past decade and offers the greatest potential for making carbon footprint smaller. To support wind turbine installation and operations many governments have put this as a top priority in their energy policy and provided many incentives to encourage the development and use of wind produced electricity [1]. Ireland has a very large potential wind energy resource and many appropriate locations for the expansion of wind energy facilities. Between 2007 and 2012 the all-island (AI) system saw a large increase in installed wind capacity from 900MW to 2100MW. By 2020 total AI wind power generation capacity is forecasted to be over 6000MW [2]. Large scale integration of wind generated electricity, however, raises problems in existing electricity grids. Due to their unpredictable and intermittent nature, wind turbines cannot be scheduled to meet steady electricity supply. Technically this variability causes supply imbalance, which will have an adverse impact on the operation of conventional power plants, thereby presenting substantial challenges to achieving relatively high penetration levels of wind energy in the electricity grid system. One attractive option, which is capable of coping with the increasing use of intermittent wind energy and has the potential to run the power generation system at constant output levels, is the Compressed Air Energy Storage (CAES) system. The CAES system uses cheap off-peak electrical energy to compress and store air in a large underground reservoir, which is released to generate electric power by running air expanders/turbines when the output from renewable energy sources is reduced or electricity demand is high, effectively providing a buffer to manage swings in energy demand and supply. Globally there are two operational CAES plants, one at Huntorf in Germany where a CAES plant of 290MW capacity was commissioned in 1978, and another 110MW plant at McIntosh, Alabama in USA, which was constructed in 1991.

The objective of this paper is to examine the technical and economic prospects of developing a CAES plant employing cavern storage excavated from the salt beds in the north east of Ireland. Ulster University (UU) is the lead partner in Project SPIRE (Storage Platform for the Integration of Renewable Energy), a research project funded by the Special EU Programmes Body (SEUPB). Cavern design data (including storage configurations, capacities and pressures) will be combined with technical and economic characteristics of existing and proposed CAES systems. To carry out this study, the process simulation software ECLIPSE is used. Modelling and simulation have been conducted for two configurations: Adiabatic Compressed Air Energy Storage (A-CAES); and Conventional Compressed Air Energy Storage (C-CAES). The fundamental process models making up the CAES systems are established and the necessary information for the process is identified. Based on design data and the results of simulation a techno-economic analysis of the process is carried out to evaluate the impacts of key parameters on the CAES systems.

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Description</th>
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<tbody>
<tr>
<td>A-CAES</td>
<td>adiabatic compressed air energy storage</td>
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<tr>
<td>BESP</td>
<td>breakeven electricity selling price</td>
</tr>
<tr>
<td>C-CARS</td>
<td>conventional compressed air energy storage</td>
</tr>
<tr>
<td>TES</td>
<td>thermal energy storage</td>
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2. Materials and Methods

2.1 Modelling Boundary Conditions and Scenarios

To provide a consistent basis for evaluation and comparison, both C-CAES and A-CAES systems have been modelled and analysed under the same boundary conditions. Two types of CAES plants are assumed to be capable of providing a capacity of 140MWe during on peak periods. The compression units comprise
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