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Editorial

Advances in Underground Energy Storage for Renewable Energy Sources

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The use of fossil fuels (coal, fuel, and natural gas) to generate electricity has been reduced in the European Union during the last few years, involving a significant decrease in greenhouse gas emissions. The global climate goal would be to reach zero emissions in 2050, and a reduction in the last portion of the CO_2 emissions could come from renewables, green hydrogen, and renewable-based electrification. In the current energy transition towards a sustainable economy, large-scale energy storage systems are required to increase the integration of intermittent renewable energies, such as wind and solar photovoltaics. Underground energy storage systems with low environmental impacts using disused subsurface space may be an alternative to provide ancillary services in the European electricity grids. In this Special Issue, advances in underground pumped storage hydropower, compressed air energy storage, and hydrogen energy storage systems are presented as promising solutions to solve the intermittency problems caused by variable renewable energy sources.

Nowadays, pumped storage hydropower (PSH) is the most mature large-scale form of storage technology. PHS systems are the primary technology used to provide electricity storage services to the grid, accounting for 161 GW of installed global storage capacity. PHS would need to double, reaching 325 GW in 2050. PSH systems consist of two water reservoirs at different heights. The stored energy depends on the mass of water moved and the net hydraulic head between both upper and lower reservoirs. The round trip energy efficiency is between 0.7–0.8. Topographic limitations in flat areas and environmental impacts currently hinder the development of these systems around the world. Conversely, disused underground space could facilitate the installation of underground pumped storage hydropower (UPSH) systems, where at least one water reservoir is underground. Menendez et al. [1] analyzed the economic feasibility of UPSH plants in closed mines providing ancillary services in the Iberian electricity market. Two different options of lower reservoirs were considered: (i) to make use of current mining infrastructure, and (ii) to excavate a new network of tunnels. Secondary regulations, deviation management, and tertiary regulation services considering daily turbine cycle times at full load between 4–10 h were employed to optimize the economic results. Investment costs of 366 M€ were obtained when the existing underground infrastructure was used as lower reservoir. Finally, an internal rate of return of 7.10% was estimated to participate in the Iberian ancillary services markets, considering turbine cycle times at a full load of 8 h. Due to the high investment costs, the profitability is reduced whenever a new reservoir has to be drilled.

The feasibility study of UPSH plants must also include geomechanical and hydrogeological aspects. Menendez et al. [2] studied the geomechanical performance of an underground water reservoir in a closed coal mine. Sandstone and shale rock masses were considered as rock masses to excavate the tunnel networks with a cross-section 30 m^2 and 200 m long. Three-dimensional numerical models were conducted to analyze the deformations and thickness of the plastic zones around the excavations. Systematic grouted rock bolts and reinforced shotcrete were applied as support systems. The results obtained showed that the excavation of the underground reservoir is technically feasible. Pujades et al. [3] carried out a study to determine the impact of hydrogeological features on the performance of an underground pumped storage hydropower plant in Belgium. The subsurface water exchange between the surrounding medium and the lower reservoir of UPSH plants was investigated. They developed a numerical study to evaluate the influence of groundwater exchanges of UPSH plants using abandoned mines as lower reservoirs. The hydraulic conductivity and the elevation of the piezometric head were analyzed. They concluded that water quality can deteriorate under the influence of UPSH systems when abandoned coal mines are used as lower water reservoirs. Dianellou et al. [4] carried out research considering large-scale wind and photovoltaic power plants and the potential contribution of PSH plants in the Greek power system. They concluded that the increase of PSH systems is required to integrate large-scale wind and photovoltaic power plants in non-interconnected grids.

Compressed air energy storage (CAES) systems consist of one underground reservoir where the compressed air is stored at high pressures. The pressurized air is released and expanded in the turbines in on-peak periods to produce electricity. Currently, there are two commercial diabatic compressed air energy storage (D-CAES) plants using abandoned salt caverns as subsurface reservoirs. The round trip efficiency of D-CAES systems is lower than PSH, reaching typical values of 0.4–0.5. Unlike D-CAES systems, adiabatic compressed air energy storage (A-CAES) systems include a thermal energy storage system, and therefore, fossil fuels are not required to heat the compressed air before the expansion in the gas turbines. Some researchers have determined that the global efficiency of A-CAES systems can reach 0.7–0.8. Prado et al. [5] investigated the thermodynamic performance of A-CAES plants in abandoned mines. An underground reservoir in lined mining tunnels at operating pressures from 5 to 8 MPa and two different sealing layers was considered in the simulations. Analytical and CFD numerical models were conducted for 100 charge (consumption) and discharge (generation) processes. They concluded that the air temperature and the heat transfer through the sealing layer depends on the sealing layer's thermal conductivity. Evans et al. [6] developed a study about the exergy storage capacity potential in United Kingdom's massively bedded halites. Massively bedded halite deposits existing in the UK were considered as CAES reservoirs. They concluded that the exergy storage capacity in salt caverns could provide important support to the electricity grid.

Hydrogen energy storage is a form of chemical energy storage in which the electrical power of renewable energies is converted into hydrogen. High pressures (35–70 MPa) are required to store hydrogen as a gas. Gajda and Lutyński [7] carried out an experimental study to compare the hydrogen permeability considering different materials, such as concrete, polymer concrete, epoxy resin, salt rock, and mudstone. The results obtained showed that epoxy resin can be a promising sealing liner for hydrogen storage. Hydrogeological concerns are also very important to determine the feasibility of hydrogen energy storage. Lafortune et al. [8] simulated a sudden hydrogen leak into an aquifer in France. They carried out an injection test of organic and ionic tracers and helium-saturated water to design the future protocol related to hydrogen storage.

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