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Economic Analysis of Electricity Storage Based on Heat Pumps and Thermal Storage Units in Large-Scale Thermal Power Plants

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Abstract

In this paper the financial viability of a novel storage concept, referred to as 'integrated pumped-heat-electricity storage', is assessed for both a coal-fired and a combined cycle (CC) power plant located in Germany, as well as for a concentrated solar power (CSP) plant located in Spain. The rationale of this concept is to use electricity during times of cheap wholesale market prices, e.g. stemming from a high supply of renewable energies, in order to generate thermal energy via a heat pump, since thermal energy can be stored at comparatively low cost. If the electricity demand rises again, the stored thermal energy is used to power a conventional water-steam cycle, thereby reducing the amount of fossil fuels used or enlarging the operating time of a CSP plant. A mixed integer linear program, considering the day-ahead wholesale market electricity prices and remunerations of offering tertiary control power in Germany, is employed to find an approximation of the optimal schedule for the generation in the power plant as well as for the purchase and the sale of electricity. The financial viability is assessed using net present value (NPV) and real options analysis. Storing electricity to profit from temporal arbitrage is found to be unprofitable, since the (conservatively estimated) costs of thermal storage units are still too high. The largest part of the revenues stems from the remunerations of offering tertiary control power. Therefore, while the utilization of heat pumps, which are estimated to have rather high costs, is not profitable, employing electric heaters without storage units is found to be economically viable for a coal-fired and a CC power plant in Germany. Here, NPV and real options analysis yield the same result, i.e. to invest immediately in such an application. In Spain, offering tertiary control power is presently not remunerated, but only the call-offs of tertiary control energy, which are not considered in the mixed integer linear program. Consequently, employing electric heaters in CSP plants in Spain is found to be not financially viable either.

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Nomenclature

CC	Combined Cycle
CSP	Concentrating Solar Power
(I-)PHES	(Integrated) Pumped-Heat-Electricity Storage
MILP	Mixed Integer Linear Programming/Program
NPV	Net Present Value
O&M	Operation and Maintenance
RTE	Round-trip efficiency
TCE	Tertiary Control Energy
TES	Thermal Energy Storage

1. Introduction

By signing the Paris Agreement, most countries in the world declared that they would strive to prevent an increase of the global average temperature in the atmosphere of more than 2 °C by decreasing the emission of greenhouse gases. One way to limit such emission is to use renewable energies, like wind and solar power, instead of burning fossil fuels, for the generating of electricity. This approach is favored, for example, by Germany and Spain. However, the supply of wind and solar power does not usually follow the demand, resulting in the need for energy storage or for the curtailment of supply. Integrating large amounts of renewable energies requires bulk energy storage units with low energy costs. Currently, pumped storage hydro power plants are most often used as bulk energy storage units, yielding power costs of about 1400 € kW^{-1}, energy costs of 140 € kW^{-1}, and a round-trip efficiency (RTE) in the order of 70-82%. Another approach, which is still under research, is that of using advanced adiabatic compressed air energy storage units, which incur costs of about 900 € kW^{-1} (power) and 100 € kWh^{-1} (energy) and which have a similar efficiency to that of pumped storage hydro power plants [1]. However, the potential for expansion of pumped hydro is quite limited in most countries, and both storage technologies have special site requirements. Moreover, other mature technologies yield significantly higher energy costs, e.g. 550 € kWh^{-1} for Li-ion batteries, disqualifying them for bulk storage applications.

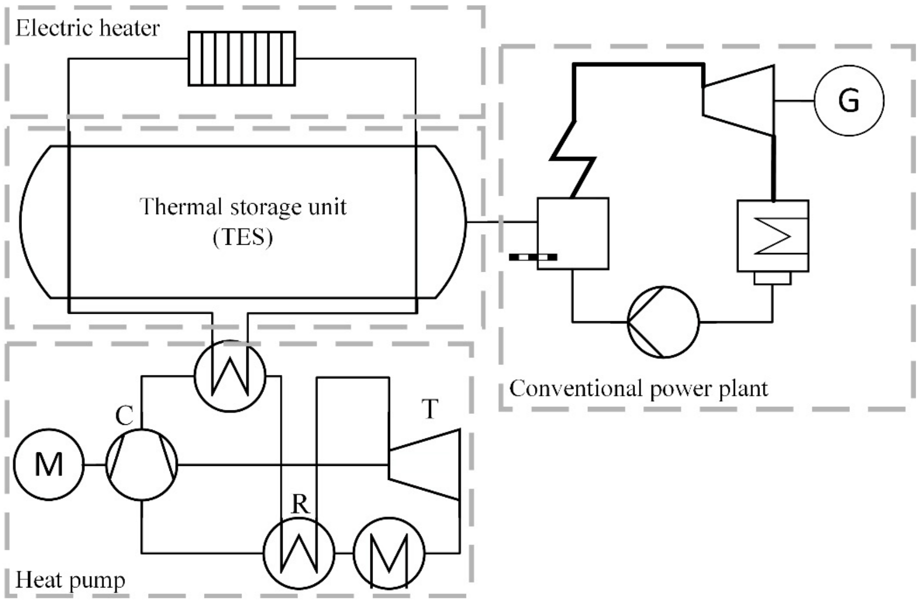

Fig. 1 Scheme of the I-PHES concept. During the charging process, heat is provided by a heat pump or an electric heater and supplied to a TES. When the storage unit is discharged, the heat from the TES is conveyed to the water-steam cycle of a conventional power plant.