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Thermo-economic design of hybrid borehole thermal energy storage systems in district heating and cooling grids

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In Germany, heating accounts for approximately two thirds of the end energy consumption in private households. It is estimated that by about 2060 the amount of energy used worldwide in cooling will overtake that used in heating. Therefore, there is a need to design efficient energy systems to supply heating and cooling loads simultaneously.

A cooling cycle cools a heat source by dissipating its heat to the environment. The rejected heat can be stored in a heat storage medium for heating purposes. The utilization of Borehole Thermal Energy Storage (BTES) systems as efficient heat sinks as well as storage media in district heating and cooling (DHC) grids has gained a lot of attention during the previous years.

However, there are still challenges that need to be resolved to pave the way for the efficient integration of such systems into DHC networks. The most important ones include high investment costs and inefficient operation when they are not properly designed. The usage of hybrid BTES systems is a useful way of alleviating these issues. A hybrid system includes supplementary heating and cooling devices, like gas boilers and cooling towers, to cover the peak demands and to regulate the induced seasonal thermal imbalance in the ground. Consequently, proper design and sizing of hybrid grids is of great importance and needs to be conducted considering both technical and economic aspects.

Exergy defines an energy system's potential to interact with its environment. As BTES systems are in seasonal interaction with ground, the exergy analysis method can be utilized as a tool for their technical assessment. By utilizing the exergoeconomic analysis method, which combines both exergy and economic principles, important information can be derived for the design of hybrid BTES systems in DHC grids.

After selecting the DHC system on campus Lichtwiese, TU Darmstadt, as a case study, different scenarios of hybrid BTES systems are proposed based on internationally accepted design recommendations. Thereafter, the conceptual models are virtualized and parametrized in TRNSYS 18. To select the optimal configuration, levelized cost of exergy product and total average exergetic efficiency are chosen as economic and technical criteria respectively. After developing a MATLAB code, the simulated TRNSYS models are coupled with MATLAB to perform multi-objective optimization of the selected objectives using evolutionary algorithms. Optimization results of different scenarios are compared with each other and the best design scenario for the case study is selected. Finally, a parametric study of the selected scenario is done to evaluate further improvement potentials.

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