HSLU Lucerne University of Applied Sciences and Arts

Engineering and Architecture
B.Sc.. Energy and Environmental Systems Engineering
Bachelor-Thesis

Exergetic analysis of Pit Thermal Energy storage integration in high temperature district heating network

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1. Problem and objective

Pit thermal energy storage (PTES), as a mature and cost-effective technology for regulating supply fluctuations of sustainable heat sources, still faces significant challenges when integrated into high-temperature district heating and cooling (DHC) networks due to pronounced temperature mismatches. This report investigates the technical feasibility and performance of integrating PTES into high-temperature DHC systems. The primary objective is to develop an exergy-based analytical framework capable of systematically evaluating different PTES integration strategies and quantitatively assessing their impacts on overall system performance.

2. Method overview

- **Selecting integrating strategies and defending system boundary**

Two representative PTES integration strategies: **PTES preheating** and **PTES back-flow** integration are selected as possible solution. The system boundaries include the DHC network and PTES while excluding heat exchangers, ensuring a consistent and comparable assessment of integration effects.

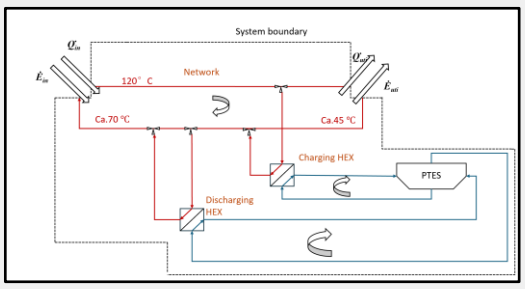

Figure: PTES preheating integration

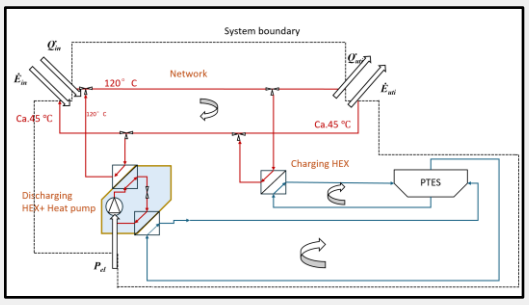

Figure: PTES back-flow integration

- **Key indicator**

The exergy utilization efficiency is selected as the key performance indicator to evaluate PTES integration. It captures both energy quantity and quality and allows direct comparison of thermodynamic performance across different integration strategies.

$$\eta = \frac{\textit{Utilized part of exergy in system}}{\textit{Total exergy input in system}}$$

Equation: Exergy utilization efficiency

- **Developing simulation modeling**

A dynamic simulation model is developed in Modelica using hourly heat demand and meteorological data representative of Swiss conditions. A five-year simulation with rule-based PTES control is applied to capture seasonal energy shifting and reduce the influence of initial conditions.

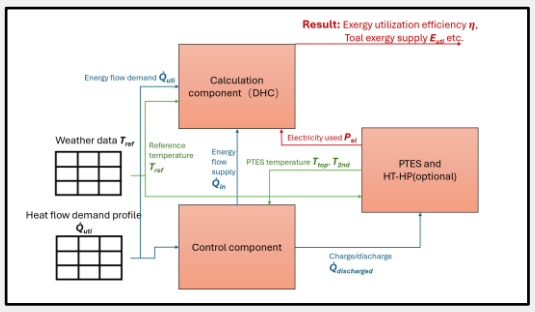

Figure: Top layer of simulation modeling

3. Results and discussion

Operating states
The PTES exhibits clear seasonal operating states, with charging during summer and discharging during winter, indicating that the control strategy effectively enables seasonal energy shifting. However, the limited discharging duration suggests that the selected storage capacity and control parameters are insufficient to fully meet winter demand, highlighting the need for further optimization.

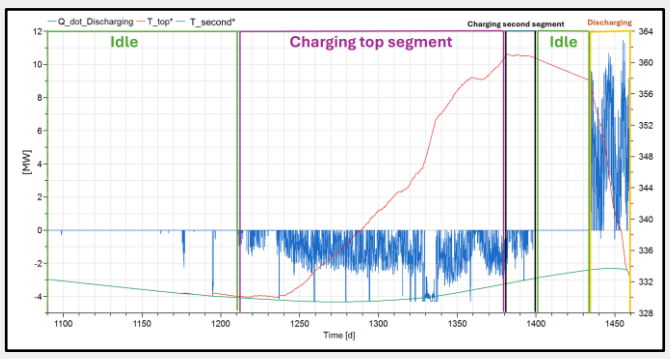

Figure: PTES operating states

Integrating Strategies Performance
The results show that PTES preheating integration achieves higher exergy utilization efficiency by avoiding direct temperature upgrading and associated exergy losses. In contrast, back-flow integration with a high-temperature heat pump incurs significant additional electrical exergy consumption, making it less efficient except in specific contexts with abundant low-carbon electricity.

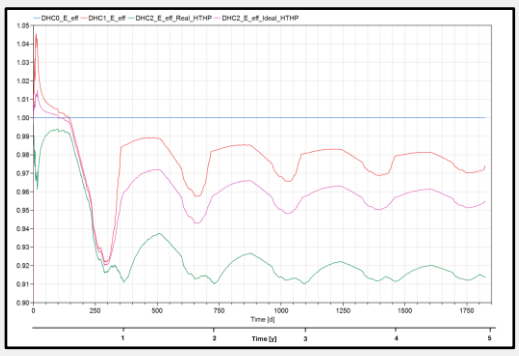

Figure: Exergy utilization efficiency of different integrating strategies

4. Conclusion and Recommendations

The exergy analysis–based framework developed in this report successfully simulates potential integration strategies between PTES and high-temperature DHC systems and evaluates their respective performance. The framework further demonstrates the effectiveness of PTES in regulating the output of sustainable heat sources. Among the two integration strategies examined, the preheating integration strategy exhibits superior performance and can therefore be regarded as the more favorable option.

References

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Dahash, A., Steingrube, A., Elci, M., (2017). A Power-Based Model of a Heating Station for District Heating (DH) System Applications. 12th International Modelica Conference, 12. https://www.researchgate.net/publication/316877537_A_Power-Based_Model_of_a_Heating_Station_for_District_Heating_DH_System_Applications

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