Optimization of Borehole Thermal Energy Storage System Design using Comprehensive Coupled Simulation Models

Graduate School of Energy Science and Engineering

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1. Introduction

Large-scale borehole thermal energy storage (BTES) is a promising technology in the development of sustainable, renewable and low-emission district heating concepts (BÄR ET AL. 2015, WELSCH ET AL. 2016). Such systems consist of several components and assemblies like the borehole heat exchangers (BHE), other heat sources (e.g. solarthermics, combined heat and power plants, industrial waste heat), distribution networks, diurnal buffer storages and heating installations. The complexity of these systems necessitates numerical simulations in the design and planning phase. Generally, the subsurface components are simulated separately from the above ground components of the district heating system. However, as fluid and heat are exchanged, the subsystems interact with each other and thereby mutually affect their performances. For a proper design of the overall system, it is thus imperative to take into account these interdependencies.

2. Coupling

Based on a TCP/IP communication we have developed an interface for the coupling of a simulation package for heating, ventilation and air conditioning (HVAC) installations (MATLAB/Simulink) with a finite element software for the modeling of the heat flow in the subsurface (FEFLOW) and the underground in-stallations.

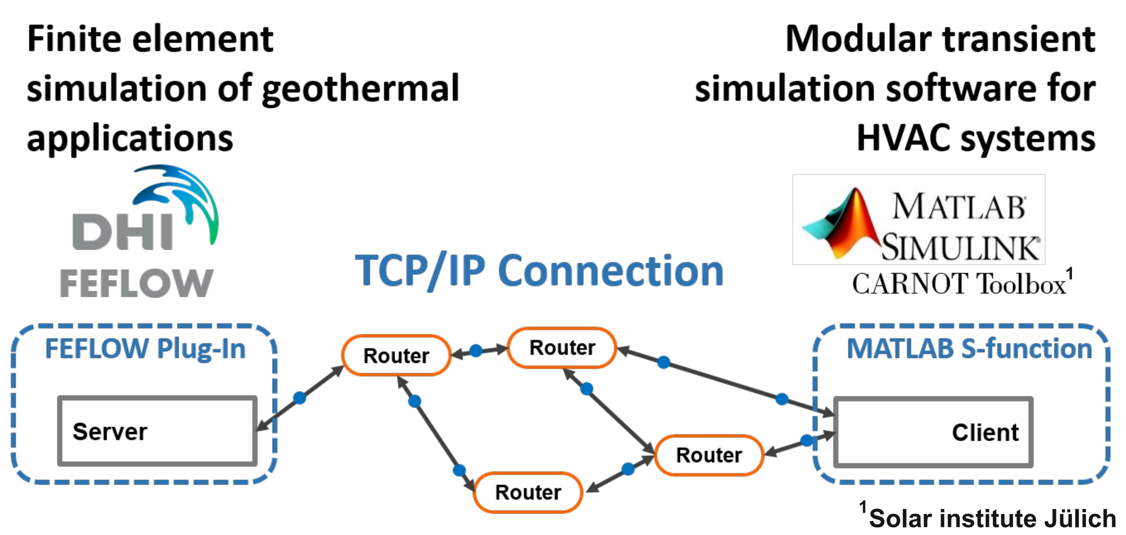


Figure 1: *Coupling concept for the simulations of the subsystems.*

3. Optimization

For the optimization, the MATLAB function *fminbnd* is used, which is based on Brent's algorithm as described in FORSYTHE ET AL. (1977). It combines a golden-section search and a parabolic interpolation for finding a minimum on a fixed interval.

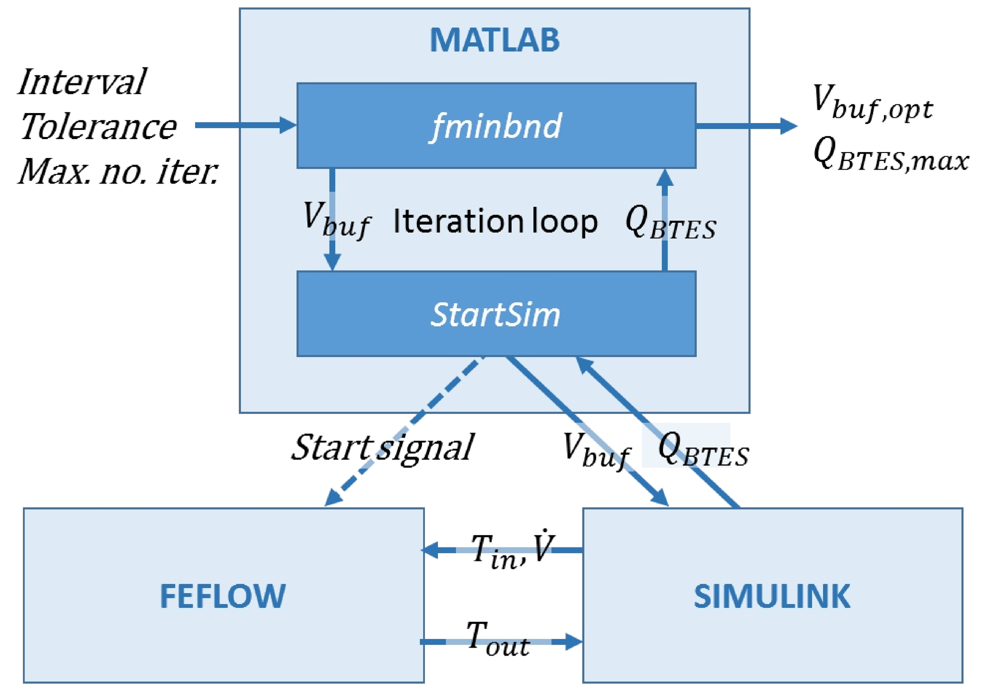
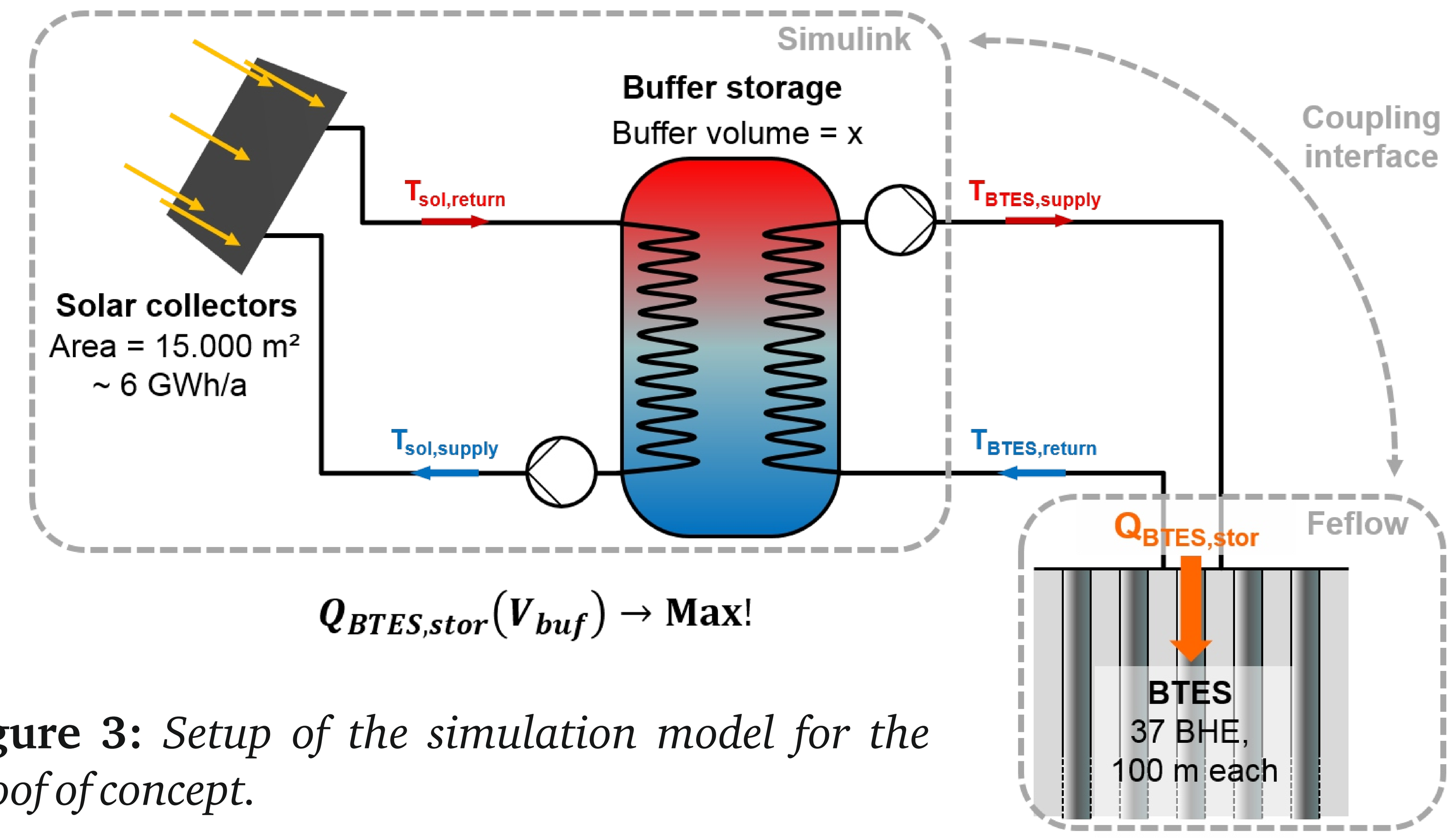


Figure 2: *Optimization concept.*

4. Proof of concept

The fictive system for the proof of concept consists of a large solar array that charges a buffer storage, which in turn charges a BTES. The optimization goal was to find an optimal buffer tank volume, for which the amount of stored heat in the BTES gets largest during three consecutive days.



$$Q_{BTES,stor}(V_{buf}) \rightarrow \text{Max!}$$

Figure 3: *Setup of the simulation model for the proof of concept.*

5. Simulation results

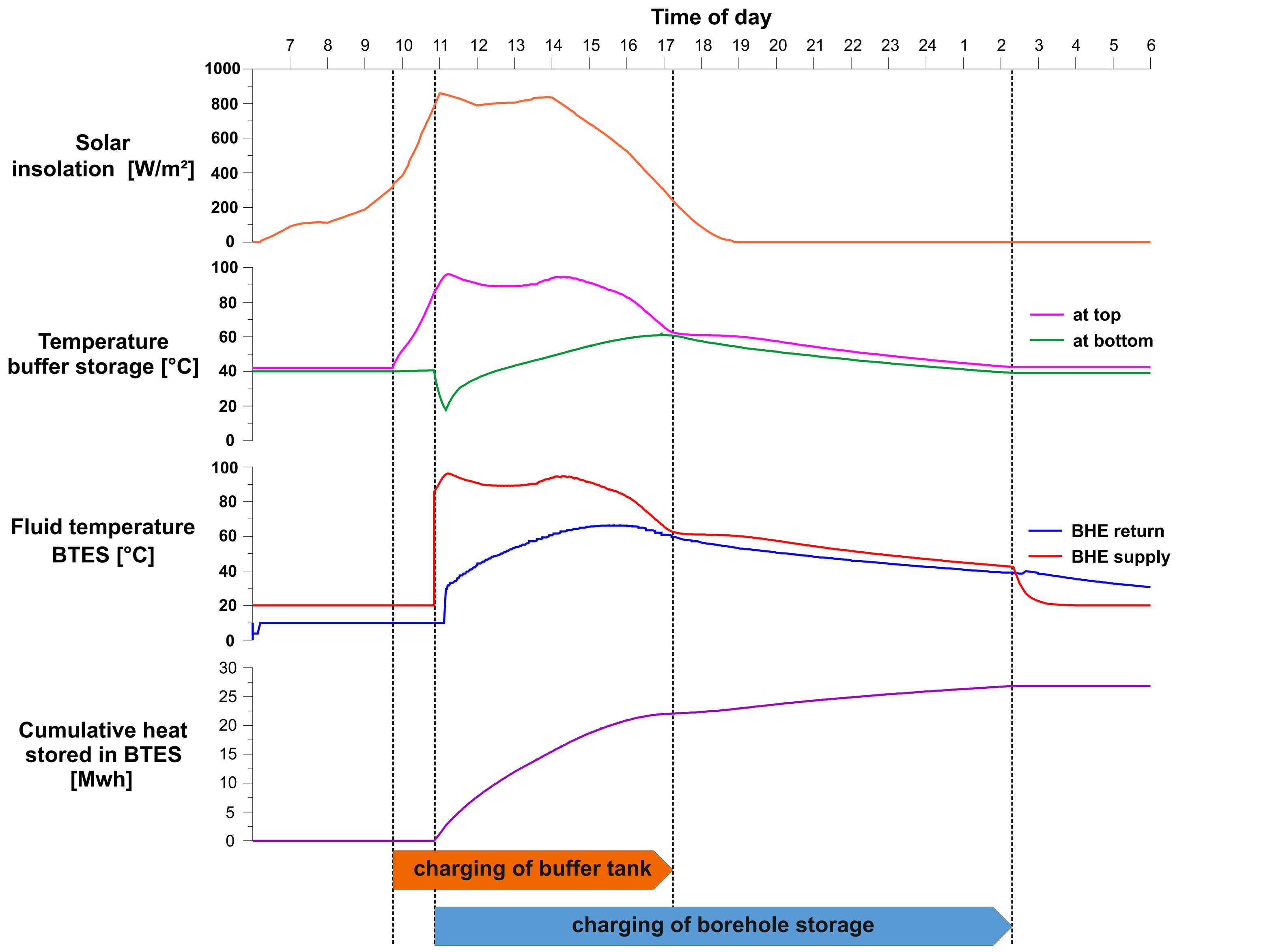


Figure 4: *Behavior of the trial coupling system during the first simulation day.*

6. Optimization results

The optimization algorithm finds a maximum in the amount of heat transferred from the buffer to the BTES at a buffer volume of about 210 m³ after 11 iterations.

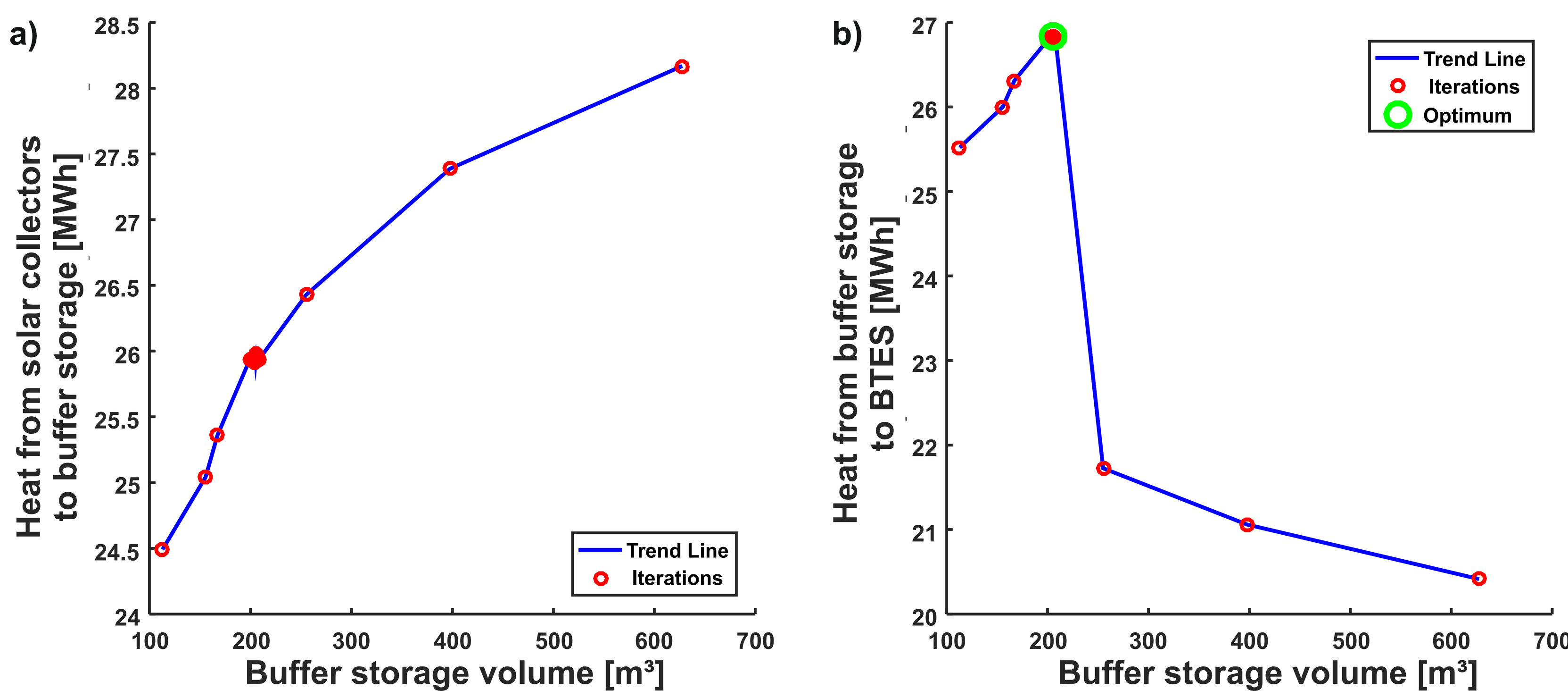


Figure 5: *Heat amounts that are transferred (a) from the solar collectors to the buffer storage and (b) from the buffer storage to the BTES for the respective iteration of the buffer volume..*

7. Conclusion

The developed coupling procedure allows for a co-simulation of all system components, considering the interaction of the different subsystems. First simulation results show a high level of detail.
Furthermore, the concept is suited for the mathematical optimization of the components and the operational parameters. Consequently, an adjustment of the system under economic and ecologic considerations can be ensured and a more precise prognosis of the system's performance can be realized.
This allows for an optimized system layout, which helps to cut costs for the installation and to maximize the ecological benefit of such renewable heating systems.

References

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FORSYTHE G.E., MALCOLM M.A., MOLER C.B. (1977): Computer methods for mathematical computations. Prentice-Hall: Englewood Cliffs, NJ

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