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Co-Simulation of Geothermal Applications and HVAC Systems

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Abstract

An interface is developed to couple the finite element program FEFLOW with the MATLAB-SIMULINK software. The TCP/IP based data exchange routine allows for a co-simulation of borehole heat exchangers and of HVAC components, so that each subsystem can be modeled in its specialized simulation environment. Hereby, the interaction of the subsystems is taken into account, which leads to a more precise representation of the systems' dynamic behavior. Furthermore, the concept supports the application of mathematical optimization algorithms that can be utilized to automatically determine several design parameters for an overall improved system performance.

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Keywords: Coupling; co-simulation; optimization; geothermal; HVAC; borehole heat exchanger; FEFLOW; MATLAB

1. Introduction

Large scale geothermal applications are eminently suitable for the substitution of fossil based energy sources, particularly in the district heating sector in combination with low supply temperatures. Furthermore, shallow and medium deep borehole thermal energy storage (BTES) systems are very promising technologies with regard to the seasonal storage of solar thermal energy [1-4]. However, these systems are most efficient if they are large enough, i.e. when the storage capacities lie in the range of several GWh of heat per year. Such a heat demand is only present

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in large district heating grids, which usually consist of several subsystems like heat sources (e.g. solarthermics or a combined heat and power plant), geothermal applications (e.g. a borehole thermal energy storage system), heat consumers (e.g. space heating systems), diurnal storages (i.e. water tanks), additional heat sources for peak load coverage (e.g. a heat pump or a gas boiler) and the distribution network. For the design and the optimization of an integrated system, numerical simulations of all subsystems are imperative. Borehole thermal energy storage systems are usually simulated with finite element programs under consideration of groundwater flow and heat transport in the subsurface. In contrast, the heating, ventilation and air conditioning (HVAC) installations are often analyzed with modular transient simulation software packages for modeling physical systems. The separate simulation of the borehole energy storage and HVAC installations is well-established, but represents a simplification. In reality, the subsystems interact dynamically with each other. The fluid temperatures of the heat generation system, the heating system and the underground storage are interdependent and affect the performance of each subsystem. Coupled simulation models, which co-simulate the subsystems are required, to take these interdependencies into account.

There are different program codes for the simulation of the interaction of borehole heat exchangers (BHEs) with the subsurface (e.g. BASIMO [5]). Here, the program FEFLOW [6, 7] is used to compute the subsurface heat transport including a one-dimensional solution for the BHEs [8, 9]. The Carnot Blockset [10] for MATLAB-SIMULINK [11] is deployed for the simulation of the HVAC components. This allows for a readily combination with the MATLAB optimization toolbox, which provides various powerful mathematical optimization algorithms.

2. Implementation

Simulation software packages from different developers usually do not contain pre-defined coupling interfaces and in addition to that, might be based on different program languages. Hence, a major challenge is to develop a robust and versatile communication architecture between them. We decided to use a client-server network connection based on the Transmission Control Protocol/Internet Protocol (TCP/IP). The TCP/IP protocol suite specifies how data has to be packetized, addressed, transmitted, routed and received at the destination. It assures that data loss is identified and corrected and it allows for a bidirectional communication. Furthermore, it offers the possibility to run the different simulation packages on separate computers (Fig. 1).

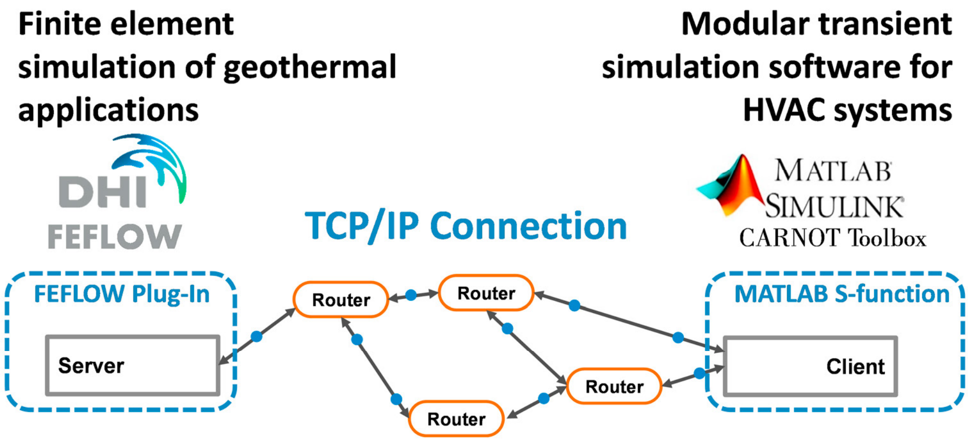

Fig. 1. Principle of the socket-client connection between FEFLOW and SIMULINK.

To establish such a connection, it is necessary that both software packages allow for the execution of proprietary source code. FEFLOW has a programming interface (IFM), which provides the possibility to read or change several model parameters during a simulation and also to execute C++ code. In SIMULINK, so called S-function blocks are available that can be integrated into the model and contain own MATLAB code or C++ code, as well.

The following routine is executed to establish the connection, send data via the interfaces and close the connection (cf. Fig. 2): FEFLOW operates as the server, which passively waits for a connection. Therefore, a TCP