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A modular approach to inverse modelling of a district heating facility with seasonal thermal energy storage

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Abstract

We use a modular approach to develop a TRNSYS model for a district heating facility by applying inverse modelling to one year of operational data for individual components. We assemble the components into a single TRNSYS model for the full system using the accumulation tanks as a central hub connecting all other components. We compare predictions of the total heat delivered to the district heating network to observed values and find a model error of 7.1% for one simulation year.

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Keywords: District heating; borehole thermal energy storage; inverse modelling.

1. Introduction

District heating systems potentially offer an economically attractive means of reducing carbon dioxide emissions by offering a more effective use of renewable resources as well as recycling of heat production which would otherwise be wasted [1]. In systems with high solar fractions, seasonal thermal energy storage is a key component in order to balance supply and demand, usually in the form of either hot water heat storage [2] or borehole thermal energy storage (BTES) [3,4].

Heat production in Denmark is to be based exclusively on renewable energy sources by 2035. Since 64% of Danish households are supplied by district heating, and the district heating network currently incorporates 86 facilities with solar collector arrays [5], there is an increasing demand for thermal energy storage. A similar development towards higher renewable fractions is underway for electricity production. The target for Denmark is to be completely independent of fossil fuels by 2050, which calls for a tighter integration of thermal and electric power systems. An important tool in supporting this transition is the development of reliable numerical models of large scale solar seasonal storage systems to aid in scenario analysis and control strategy development [6,7].

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In the present work we focus on the district heat facility in Brædstrup, Denmark, and develop and validate a TRNSYS model of the facility by applying inverse modelling to operational data at the component level. This approach serves to limit the search space for the numerical optimisation and can in principle be applied to a system of any size. The calibrated system components are used to construct a model of the entire system and predictions from this full model are finally compared to observed data

The paper is organised as follows. In Section 2 we give a brief description of the district heating plant. In Section 3 we describe a modular approach to inverse modelling of a large system and describe how the final model is constructed from the components. In Section 4 we present and discuss results. Section 5 concludes the paper.

2. System description

The district heating facility in Brædstrup delivers heat and power to approximately 1450 households. A schematic overview of the plant is given in Fig. 1.

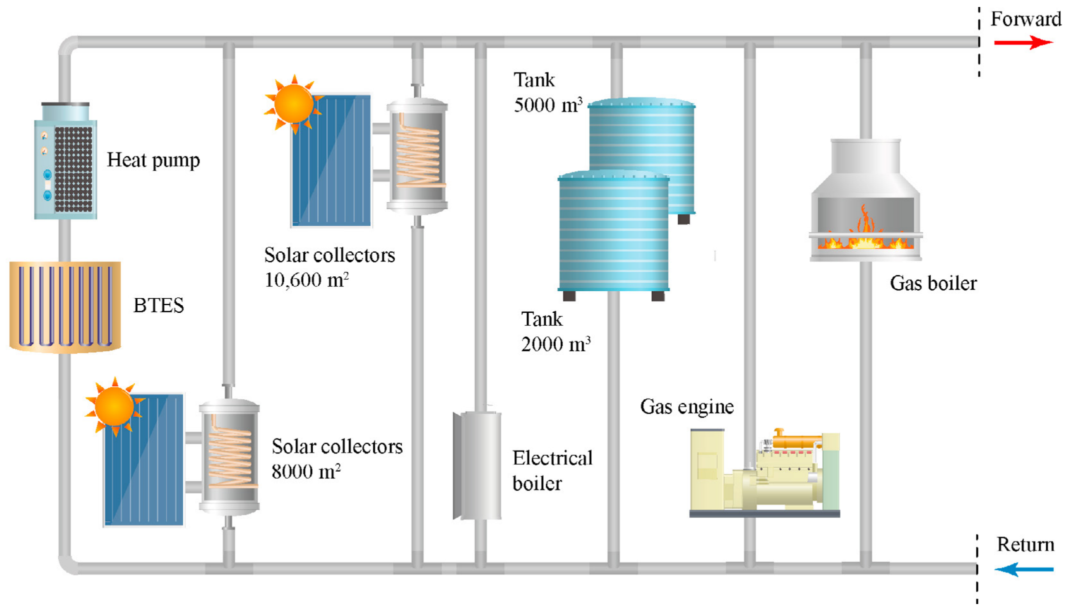

Fig. 1. Simplified diagram of the district heating facility.

The plant has two natural gas engines with a combined electrical power of 7.28 MW and thermal power of 8.0 MW. Additionally the plant has a 13.5 MW natural gas boiler, a 10 MW electrical boiler and two steel accumulation tanks with volumes 2000 m^3 and 5000 m^3 respectively. Renewable heat production is provided by two solar collector fields with individual total areas of 8000 m^2 and $10,600$ m^2 respectively. Excess heat produced by the collector fields during summer is stored in a $19,000$ m^3 borehole thermal energy storage (BTES) and retrieved using a 1.2 MW heat pump during winter.

3. Methods

We develop a TRNSYS model for the entire facility by applying inverse modelling at a component level. For each component, a separate TRNSYS model is constructed which reads the relevant input data such as inlet temperature and flow rate from an external data file. A forward simulation is run for 365 days and simulated outlet temperatures are recorded. These outputs depend on one or more component parameters e.g. the efficiency and are compared to the operational measurements. For each component a meaningful objective function is constructed to quantify the discrepancy between the observed and simulated outputs. Finally we calculate the best component parameters by

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