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

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Introduction

We develop a TRNSYS model for a district heating plant in Brædstrup, Denmark (see Fig. 1). Model parameters for the renewable components are estimated by applying inverse modelling to one year of operational data. Each component is calibrated separately as exemplified below for the borehole thermal energy storage (BTES). For the analysis of the remaining components please refer to our full paper in the conference proceedings.

Inverse modelling example - BTES

Model parameters for the BTES are the storage heat capacity \(C\) and borehole thermal resistance \(R_b\). Optimum parameters are identified by minimising the objective function

\[
\varphi = \sum \left( T_{\text{out}}^{(s)} - T_{\text{out}}^{(m)} \right)^2
\]

(1)

It is important to preheat the BTES in TRNSYS so that for simulation time \( t < 0 \) the storage average temperature is

\[
T_{\text{BTES}} = \frac{T_{\text{max}} + T_{\text{min}}}{2} + \frac{T_{\text{max}} - T_{\text{min}}}{2} \sin(\omega(t + \theta))
\]

(2)

We estimate \( T_{\text{max}}, T_{\text{min}}\) and the phase \( \theta\) based on historical data before minimising the objective function in Eq. (1) to obtain a storage specific heat of 2.00 MJ/m3/K and borehole thermal resistance of 0.018 m·K/W.

The simulated energy is compared to observations in Fig. 2.

Fig. 2: Simulated and observed energy injected and extracted from the storage. Simulation start time is January 1th 2014. The first approximately 80 days corresponds to energy extraction.

Total model

The individually optimised components are collected in a total model for the full system using the tanks as a central hub. Note the two tanks are connected differently depending on the season as indicated in Fig. 3.

Fig. 3: Flow paths during summer and winter operation. In the model the return flow from the district heating network is split with \( m_{\text{conv}} \) passing through the conventional production sources and the remainder going to the tanks.

Conventional production is modelled using the measured thermal power and redirecting part of the return flow from the district heating network (see Fig. 3) such that

\[
P_{\text{conv}} = m_{\text{conv}} \cdot c_p \cdot (T_{\text{set}} - T_{\text{DH}}^{(\text{ret})})
\]

(3)

where \( P_{\text{conv}} \) is the measured thermal power from the conventional sources, \( m_{\text{conv}} \) the redirected flow to be calculated, \( T_{\text{set}} \) the temperature set-point for the conventional sources and \( T_{\text{DH}}^{(\text{ret})} \) the measured return temperature from the district heating network.

We run the full model for 365 days and compare the simulated energy delivered to the district heating system to the measured values in Fig. 4. The final error in the predicted energy is 2.75 GWh corresponding to a simulation error of 7.1 %.

Conclusion

We have developed a TRNSYS model for a district heating facility by applying inverse modelling to one year of operational data for each component in the system.

We collect the optimised components in a single model of the full system using the tanks as a central hub. The full model yields a simulation error of 7.1 % for the delivered energy.