Comparative Analysis of Price-based Control Strategies for a High Temperature Thermal Energy Storage System

Presenter:
Tao Yang
Center for Energy Informatics
University of Southern Denmark

Authors:
Tao Yang¹, Isabela Zuluaga¹, Konstantin Filonenko², Christian Veje³
¹Center for Energy Informatics, University of Southern Denmark
²DTU Compute, Technical University of Denmark
³Department of Mechanical and Electrical Engineering, University of Southern Denmark

America Modelica Conference 2022, October 26-28, 2022
Agenda

• Background and motivation
• Models
• Simulation setup
• Preliminary results
• Conclusions and future works
The common use energy storage systems to deal with mismatch between energy demand and supply
The use of advanced control strategies (eg. MPC) to enhance energy efficiency
A lot of works focus on MPC for water-based thermal storage
In this work, an MPC for high temperature thermal storage (HTTES) systems is developed
Models

Schematic diagram of the HTTES

**Charging**

\[
\dot{Q}_{ch} = \dot{Q}_{ch,in} - \dot{Q}_{ch,out} = \dot{m}_{ch} \cdot c_{air} \cdot (T_c - T_s)
\]

\[
P_{el} = \dot{m}_{ch} \cdot c_{air} \cdot (T_c - T_s)
\]

**Discharging**

\[
\dot{Q}_d = \dot{Q}_{d,out} - \dot{Q}_{d,in} = \dot{m}_d \cdot c_{air} \cdot (T_s - T_{sr})
\]

**Heat loss**

\[
\dot{Q}_{loss} = U \cdot A_s \cdot (T_s - T_{amb})
\]

Rankine cycle
Models

- The rock is Swedish diabase
- The volume of the rocks is 1.5 m$^3$, and the mass of the rocks is 2495 kg. The storage measures 1 m by 1 m by 1.5 m

### Specification of relevant physical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat capacity of air</td>
<td>[J/kg · K]</td>
<td>$c_{p_{air}}$</td>
<td>1000</td>
</tr>
<tr>
<td>Density of Swedish Diabase (solid)</td>
<td>[kg/m$^3$]</td>
<td>$\rho_{r,s}$</td>
<td>3007</td>
</tr>
<tr>
<td>Volumetric heat capacity of Swedish Diabase (solid)</td>
<td>[J/m$^3$ · K]</td>
<td>$c_{p} \cdot \rho_{r,s}$</td>
<td>3,824,900</td>
</tr>
<tr>
<td>Specific heat capacity of Swedish Diabase (solid)</td>
<td>[J/kg · K]</td>
<td>$c_{p}$</td>
<td>1272</td>
</tr>
<tr>
<td>Density of Swedish Diabase (packed bed)</td>
<td>[kg/m$^3$]</td>
<td>$\rho_{r,p}$</td>
<td>1663.33</td>
</tr>
</tbody>
</table>
Model predictive controller

Overview of the simulation setup

Implementation of model predictive controller
Model predictive controller

- Control model: nonlinear state space model

- Economic MPC

\[
J_{rev} = - \sum_{i=k}^{P} \left( \frac{P_{g,i}}{3.6 \cdot 10^9} \cdot \text{spot}_{c,i} + \frac{\dot{Q}_{c,i}}{3.6 \cdot 10^9} \cdot \text{price}_{DH,i} - \frac{P_{el,i}}{3.6 \cdot 10^9} \cdot \text{spot}_{c,i} \right)
\]

Subject to:

System dynamics

\[100 \, ^\circ C < T_s < 600 \, ^\circ C\]

\[-3 < u < 3\]

- Prediction horizon: 24 h
- Control horizon: 15 minutes
Rule-based controller

Control logic of RBC 1

Start

Price <= Pricemin

Yes → MODE 1 Charge

No → Price >= Pricemax

Yes → MODE 2 Discharge

No → Pricemax >= Price >= Pricemin

Yes → MODE 3 Stop

No

Control logic of RBC 2

Start

Price <= Pricemin && Ts<Tmax

Yes → MODE 1 Charge

No

Price >= Pricemax && Ts>Tmin

Yes → MODE 2 Discharge

No

Pricemax >= Price >= Pricemin && charging

Yes → MODE 3 Keep charging

No

Pricemax >= Price >= Pricemin && discharging

Yes → MODE 4 Keep discharging

No

Other conditions

Yes → MODE 5 Stop
Rule-based controller

- **Pricemin = 258 DKK/MWh**
- **Pricemax = 358 DKK/MWh**

**KPI for simulating 7 days**

<table>
<thead>
<tr>
<th>KPI</th>
<th>RBC 1</th>
<th>RBC 2</th>
<th>RBC 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total net revenues [DKK]</td>
<td>86</td>
<td>105</td>
<td>171</td>
</tr>
</tbody>
</table>

Control logic of RBC 3
Preliminary results

<table>
<thead>
<tr>
<th>KPI</th>
<th>RBC 3</th>
<th>MPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total net revenues [DKK]</td>
<td>171</td>
<td>469.7</td>
</tr>
</tbody>
</table>
Conclusions and future works

- The preliminary results show that MPC outperforms RBC. However, the current RBC performance highly relies on the choice of electricity price threshold.

- The continuation of the work involves development of a more detailed emulation model.

- The continuation of the work involves tuning the Modelica-based RBC settings based on price margin including customizing different RBCs under different price scenarios.
THANK YOU FOR YOUR ATTENTION

Presenter:
Tao Yang
Email: taoy@mmmi.sdu.dk
Center for Energy Informatics
University of Southern Denmark