Digital twins as enablers for waste heat recovery with thermal energy storage
Felix Birkelbach | Energy Future Industry 2023, May 9th-11th, Göteborg
Challenges in waste heat recovery

- Heat sources that could easily be integrated are already integrated.
- To utilize remaining heat sources, special solutions are required.

- Both the technology and operation strategies have to be tailored to the special requirements of the process.
Use case: waste heat recovery from crucible gas

SCHWARZMAYR, P.; KASPER, L.; BIRKELBACH, F.; HOFMANN, R.: DEVELOPMENT OF A DIGITAL TWIN PLATFORM FOR INDUSTRIAL ENERGY SYSTEMS, APPLIED ENERGY SYMPOSIUM, 2022
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Use case: process integration
Packed bed thermal energy storage

- Utilize sensible heat to store thermal energy
- Storage container filled with heat storage material
- Robust: Can be operated in harsh operating conditions.
- Cheap: Comparably cheap materials

- Operation strategy has to be adapted to the amount of clogging
- → Digital twin platform
Digital twin for a packed bed thermal energy storage

Insights from the project 5DIndustrialTwin

In collaboration with:
Lukas Kasper
Paul Schwarzmayr
Store dimensions: Ø 0.5 x 2 m
- Insulation: 100 mm of ceramic wool + 80 mm of rock wool
- Max. charging temperature = 400 °C
- Storage capacity = 50 kWh (with ΔT = 300°C)
- Max. charging power rate = 33 kW (with ΔT = 300°C)
- Storage Volume = 0.405 m³
- Storage material: LD-slag (mostly calcium oxide)
- Mass of storage material = 900 kg
- Grain size of storage material = 16–32 mm
- 49 PT100 temperature sensors inside the packed bed
Digital twin framework
Implementation: physical entity

- PBTE test-rig
- equipped with 49 temperature sensors
- SCADA system:
  - XAMControl for data acquisition and process control
  - OPC UA aggregation server for information modelling and MQTT integration
3 dimensional simulation model
- **Finite volume method**
- soft sensors models for malfunctioning temperature sensors
  - purely **data driven models**
  - models are created **on-demand** based on knowledge stored in the ontology
- Model management allows to add and replace models during operation
Implementation: connection dimension

- **MQTT Broker** as central communication hub
- topic-based **publish/-subscribe functionality**
- each of the other four dimensions is connected as a **client**

- Clients can **subscribe and publish** to different topics
- Broker is responsible for receiving, filtering and sending messages
Implementation: data dimension

- relational **sql database** for the storage of **runtime data** from the **physical entity**
- runtime data is integrated via **ontology-based data access**
- **knowledge representation** via ontologies
- **ontology stores semantic data** about plant equipment, topology and instrumentation
Implementation: service dimension

- Contains services in form of independent microservices
- Data acquisition, soft sensor service, fault detection, ...

- Service orchestration via a workflow engine
- Workflows are defined as BPMN workflows
Digital twin platform: Integrating services

- Services can interact with each other
- High level services can access information from low-level services

Example:

- Data pruning service that provides clean data to all high-level services
- Automatic soft-sensor service
Evaluation results

Sensor failure
SOC error
Soft sensor

Adaptable operation optimization

- Use measured data to regularly update thermal models of TES
- Use up-to-date models in operation optimization

Condition monitoring for maintenance

- Use temperature information to track the condition of TES
- Make maintenance decisions based on actual state of TES

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\frac{dT}{dt} \approx \Delta T + b
\]

\[
\frac{dq}{dt} = \alpha \Delta T
\]
Methods and applications of digital twins
Insights from IEA IETS Task XVIII Subtask 2
The term digital twin

- No exact definition
- Used for quite different things

Nevertheless the concept of the “Digital Twin” drives a lot of innovation
- Advanced modeling
- Experimental identification
- Data science
- Artificial Intelligence
Some insights from our questionnaire

What is the current state regarding the deployment of your digital twin?

- Discussion and preparation phase: 19%
- Planning phase: 24%
- Implementation phase: 9%
- Operation phase: 48%
Some insights from our questionnaire

- Why did your company decide to employ a digital twin?

<table>
<thead>
<tr>
<th>Reason</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Energy/plant efficiency</td>
<td>70%</td>
</tr>
<tr>
<td>Ready for future challenges</td>
<td>50%</td>
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<tr>
<td>Cost savings</td>
<td>40%</td>
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<td>Reliability/stability of process</td>
<td>30%</td>
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<tr>
<td>Modernization</td>
<td>20%</td>
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<tr>
<td>Strategic decision</td>
<td>0%</td>
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<tr>
<td>Increase competitiveness</td>
<td>0%</td>
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</tbody>
</table>
Opinion and expectations: How much do you agree with the following statements?

- In general, DTs support the competitiveness in the future.
- In general, DTs are an integral part of our R&D strategy.
- In general, DTs are essential for reaching CO2 reduction goals.
- In general, DTs enable new business models.
- In general, DTs fundamentally change the energy management of my company.
Digital twins allow to couple physical devices with advanced algorithms.

They can enable green technology for challenging applications.

Increase efficiency, reduce emissions, make investments in green technology profitable.
Some excess heat flows are difficult to recover because of the harsh process conditions. For this talk we consider the heat recovery from crucible gas in a steel mill as a use case. We propose packed bed thermal energy storage in combination with a digital twin. The digital twins monitors the thermal energy storage and provides a set of services that enable its effective operation under these harsh conditions.

We present the employed digital twin architecture and an automatic soft sensor service to showcase its capabilities.

Finally we also share some insights from the IEA IETS Task XVIII Subtask 2 on Applications and Methods of Digital Twins.