INTEGRATED NETWORKS

Simulating smart coupled district heating and electrical distribution networks

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Heat and power networks transform from centralized fossil fuel based generation to:
• distributed generation & storages
• prosumers
• intelligent control
• low energy buildings
• increased sector integration
• …

Complexity of multi-domain system requires
→ assess multi-energy use cases
→ test “smart” control before roll-out
METHOD DEVELOPMENT: RELEVANT PHENOMENA AND TIME SCALES

focus of presented method

electric distribution
- electromechanical
- electromagnetic
- voltage stability
- topology changes
- frequency fluctuations
- load characteristics

district energy
- flow reversals
- temperature changes
- pressure distribution
- weather changes
- waterhammer
- load characteristics
- topology changes
- economic dispatch
- unit commitment

control decisions
- closed-loop control
- load forecasting
- design choices
- protective systems
- optimal set-points
- maintenance scheduling

time scale: ms s m h d y
COMBINED ASSESSMENT METHOD

- **No single tool** that covers all necessary domains:
  - thermo-hydraulic models
  - electric distribution networks
  - advanced control algorithms

- **Co-simulation** is a possible solution
  - allows use of suitable tools for each domain → diverse co-simulation setups
The Functional Mock-up Interface (FMI) specification has been developed to encapsulate and link models and simulators.

- currently supported by > 100 tools
- see: https://www.fmi-standard.org/

The FMI++ Library is based on FMI

- open-source development
- cross-platform and cross-language
- allows cherry picking of tools and modeling paradigms
METHOD DEVELOPMENT: FOCUS ON OPERATIONAL ASSESSMENT

- **Physical system** modeling
  - Electric distribution modeling approaches (quasi-static, dynamic, …)
  - District heating modeling approaches (hydraulics, temperature propagation, dynamics, …)

- **Control system** modeling
  - Discrete, continuous, …
  - Rule-based, optimal, …
  - Supervisory, local, …
  - Central, distributed, hybrid, …
PHYSICAL SYSTEM MODEL: DISTRICT HEATING NETWORK

- **Dynamic model** for district heating network
  - Transient thermal models
  - Quasi-static hydraulic models
- Developed **open model library** for district heating networks
  - Based on validated and open-source models
PHYSICAL SYSTEM MODEL: COUPLING

• Models are **coupled sequentially**
• Coupling units are modeled as PQ-loads in power network model
• Mean power consumption is updated every $\Delta t$

$$P_{qs}(t) = \frac{1}{\Delta t} \int_{t-\Delta t}^{t} dx \, P_j^{dy}(x)$$
PHYSICAL SYSTEM MODEL: ELECTRICAL DISTRIBUTION NETWORK

- Solve **power flow equations** at each time step

\[ I_a = \sum_{b=1}^{n} Y_{ab} V_b \]

- Suitable to study medium to long term effects of time-varying loads and generators
ADVANCED CONTROL MODEL: FEEDBACK

- **Feedback** from physical system to control system
  - Closed-loop control
  - Corrects for modelling differences in physical system and advanced control model
ADVANCED CONTROL MODEL: RUN CONTROL FUNCTION

- **Advanced control** systems
  - Closed-loop control using feedback
  - Use of MPC or data-driven approaches
  - FMI enables use of various different tools, e.g.: python
EXAMPLE APPLICATIONS: PHYSICAL SYSTEM

- **District heating** network simulation
EXAMPLE APPLICATIONS: PHYSICAL SYSTEM

- Electric network simulation
EXAMPLE APPLICATIONS: PHYSICAL SYSTEM

- **Building** demand and generation
  - Detailed secondary side
  - Time series input files
  - Decentral DHW electric boosters
EXAMPLE APPLICATIONS: A) LOWER SUPPLY TEMPERATURE

• Example A: Lower network supply temperature
  • Local electric booster heaters guarantee domestic hot water supply
  • Lower supply temperature in times of no space heating demand
EXAMPLE APPLICATION:
A) LOWER SUPPLY TEMPERATURE

detailed network insights
EXAMPLE APPLICATION:  
A) LOWER SUPPLY TEMPERATURE
EXAMPLE APPLICATIONS:
B) SMART ELECTRIC BOOSTER HEATER

• Example B: Smart electric booster heater
  • Avoid simultaneous use of domestic hot water and space heating to lower peak heat demand
  • Flexibility option for electric network, e.g., increase self-consumption of PV

grid-friendly MPC of electric booster heater

\[
\begin{align*}
\text{minimize} & \quad \sum_{k=1}^{N_w} \left( p_{RL}[k] \right)^2 + w_2 \cdot p_{DH}[k] \cdot Q_{DH}[k] \\
\text{subject to} & \quad \text{zero-dimensional EBH dynamics & temperature constraints}
\end{align*}
\]
EXAMPLE APPLICATION:
B) SMART ELECTRIC BOOSTER HEATER

test impact of different forecast methods or control implementations
EXAMPLE APPLICATION:
B) SMART ELECTRIC BOOSTER HEATER

self-consumption of local PV generation
EXAMPLE APPLICATION: B) SMART ELECTRIC BOOSTER HEATER

- Reduced heat demand peaks in district heating

Diagrams showing aggregated DH power and excess power from PV, with comparisons between uncoupled, simple, MPC-p, and MPC-n models.
USE OF METHOD

- Control assessment
- Design validation
- Digital twinning
- „What if?“ analyses
- Understanding and playing around with complex systems :-)

RESOURCES: OPEN-SOURCE & PROPRIETARY

• District heating network model using Modelica/Dymola
  • Dymola: https://www.3ds.com/de/produkte-und-services/catia/produkte/dymola/
  • DisHeatLib: https://github.com/AIT-IES/DisHeatLib

• Electric distribution network model using pandapower
  • pandapower: https://pandapower.readthedocs.io/
  • pandapowerFMU: https://github.com/AIT-IES/pandapowerFMU

• Control implementation using Python/Pyomo
  • Python: https://www.python.org/
  • Pyomo: http://www.pyomo.org/
  • FMI++ Python Interface: https://pythonhosted.org/fmipp/

• FMI-based co-simulation using FUMOLA/Ptolemy II
  • FUMOLA: https://sourceforge.net/projects/fumola/
  • Ptolemy II: https://ptolemy.berkeley.edu/ptolemyII
THANK YOU!


Control assessment in coupled local district heating and electrical distribution grids: Model predictive control of electric booster heaters, B. Leitner, E. Widl, W. Gawlik and R. Hofmann, in Energy, under review - minor revisions.