Data-Driven Model Predictive Control of a District Heating Network

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INTRODUCTION

New housing development in North Rhine-Westphalia, Germany, 120 residential units, 1 GWh annual heat demand

Source: www.google.de/maps/ (2021)
INTRODUCTION

4th generation heating network (flow 55°C, return 35°C)

Heat generator for storage tank charging
• Combined Heat & Power (CHP)
• Electric Heat Pump (HP)
• Solar Thermal Plant (STP)
• Heating rod

Securities
• Gas boiler secures supply
• System ensures device operation

Natural gas: Costs from purchase (incl. taxes)
Electricity: Costs/revenues from purchase/sale + state subsidies

Optimal operation + connection to (electricity) market?
CHALLENGE I

Transmission system operator ensures a balanced power grid

- Market participants must declare planned energy quantities for the following day
- Energy quantities result from planned operation (Schedule)
- Deviations from planned energy quantities (results in balancing energies) can lead to high costs

Forecasts and informations for the following day → Decision for a schedule → Minimization of balancing energy

Challenge
Creation of an optimized schedule and compliance with the declared energy quantities
CHALLENGE II

Thermal storage allows decoupling of heat demand and heat generation
Possible case: Exclusively electricity price-led operation of CHP + HP?
➢ Operation of CHP + HP "limited" by dependencies:

Challenge
Prediction of boundary conditions and system response e.g. temperature distribution of the heat storage required
SOLUTION

Simulation of the system (e.g. using MATLAB/Simulink), embedding in optimization

- High computational effort
  - Few minutes for one simulation and evaluation (one Schedule)
  - 10000+ cycles (hours!) for optimal schedule
- Consideration of system changes? (fouling, …)

**Optimization-Framework** → Optimal schedule + corresponding energy quantities
SOLUTION

Data-based approximation of thermal and electrical behavior

- Machine Learning (ML) for fast and accurate approximation
  - Only milliseconds incl. evaluation
  - Few minutes for optimal schedule
  - Approximates changes in system behaviour (based on measured data)

Optimization-Framework → Optimal schedule + corresponding energy quantities

Previous Day:
Minimizing ecology and/or economics

Fulfillment Day:
Minimizing deviations
RESULTS

• Comparison of different approaches to **cost-optimal** control
• Scheduling in simulation-environment, 3 months (April-June)
• Boundary conditions (heat load, global radiation, etc.) with uncertainties

• Case 1: Detailed **S**cheduling + **A**djustment (DSA)
  • Optimale scheduling using ML as described before

• Case 2: **E**lectricity-led **S**cheduling (ES)
  • No prediction of systems state, optimized schedule to achieve highest revenue

• Case 3: **H**eat-led **S**cheduling (HS)
  • Rule-based (non-predictive), simple prediction based on energy balances

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RESULTS

Cumulative Operating Costs

- In general: Revenues and subsidies for CHP electricity lead to negative operating costs

- Electricity price-led schedule:
  - Optimal operating costs by exhausting the CHP unit

- Storage temperatures influences CHP operation (efficiency + protection)
  - Deviations from schedule
RESULTS

Cumulative Operating Costs

Cumulative Balancing Energies

Costs for Balancing Energies:

Median: 25€/MWh
RESULTS

Cumulative Operating Costs

Cumulative Balancing Energies

Total Costs

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SUMMARY

- Hybrid Systems require detailed prediction of future systems state for optimal control and scheduling
  ➢ Machine Learning for detailed approximation better than simple models based on energy balance
- Cost stability increase with complexity of the method
- Adjustments on fulfillment day reduce balancing energies significantly (-30%)
- Outlook: Boundary conditions will change, emissions from natural gas will become more important to consider = Electricity-led operation won’t be best choice

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THANK YOU FOR YOUR INTEREST!

IF YOU HAVE QUESTIONS

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