Advanced Simulation and Control Methods for Operation, Planning and Control of District Heating Networks

A Dynamic Simulation Approach

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4th Generation of District Heating
How to handle such requirements?

Simulation Tools Available

In order to design, operate and control future networks, sophisticated dynamic modelling and simulation tools are necessary.
## Dymola- Modelica Strengths and Weaknesses

### Strengths

- Detailed representation of complex systems and their dynamic behavior
- Wide range of available libraries in development for energy systems
- Suitable platform for Dynamic Optimisation tasks

### Weaknesses

- Dynamic models have their limitations due to high computational effort
- Not feasible for simulation of very large networks
DH Network Control and Operation

\[ Q = f(\Delta P_{\text{supply}}, T_{\text{supply}}) \]
DH Network Control and Operation

\[ Q = f(\Delta P_{\text{supply}}, T_{\text{supply}}) \]

\[ T_{\text{supply}, \text{gas}1} \quad Q_{\text{supply}, \text{gas}1} \]

\[ T_{\text{supply}, \text{gas}2} \quad Q_{\text{supply}, 2} \]
Network Operation— How to optimize for more efficient DH operation?

- **Objective function**
  \[ F = \sum_{i=1}^{n} f_i(P_i) \]

  - Cost function of thermal unit i
  - Power output of thermal unit i
  - Total number of thermal units

- **Constraints:**
  - Total generation to meet total demand
  - Max/Min outputs of production units
  - Max/Min ramp up/ramp down rates of production units

- **Supply temperature optimization** is often used to minimize the objective function. Dynamic simulations are needed to account for delay times in temperature propagation across the network.
How to simplify a network’s Topology?

Source: Energie Graz
Network Aggregation

- Done in accordance with the thermo-hydraulic laws to conserve as best as possible:
  - Total fluid volume in network
  - Overall heat losses
  - Sum of mass and heat flows to all consumers
  - Temperatures at remaining nodes
  - Delay times at remaining nodes

- Error is unavoidable and scales proportionally to how much the networks is simplified from the original. This level of simplification is defined as the aggregation depth $\phi$:

$$\phi = 1 - \frac{\text{Number of consumers in aggregated network}}{\text{Number of consumers in original network}}$$
Network Aggregation – Comparison of Two Methods

German Method

- Supports loop structures
- Temperatures in all nodes are conserved
- Pressure drops in pipes considered
- Heat loss coefficients are adjusted and can be negative

Danish Method

- Does not support loop structures
- Temperatures nodes are not conserved
- Pressure drops in pipes are not considered
- Heat loss coefficients are independent of temperatures
Network Aggregation – Case Study

- Original Network: 146 consumers.
- Tree like grid structure
- Single Production site.
- Total pipeline length: 7km
- Capacity 2.5MW
Case Study Setup

- The aggregated networks were compared with the original network over a 48 hour timeframe with the following profile at the production site:

![Graph showing Supply Temperature and Return Temperature over time.]

![Graph showing Total Load over time.]

Case Study Setup

- Both German and Danish Aggregation methods were carried out on the network to assess the impact on:
  - Mass flow rates at the producer
  - Heat flow rates at the producer
  - Heat losses
  - Delay times
  - Simulation time
Network Aggregation- Case Study 98% Aggregation Depth
Network Aggregation – Case-Study 98% Aggregation Depth
Case Study Results Aggregation

- Comparison of Heat and Mass Flows at producer for both German and Danish aggregation methods at 98% aggregation depths
Case Study Results Aggregation

- Error comparison for German Method
Case Study Results Aggregation

- Error comparison for Danish Method
Standard Deviation Comparison
Dynamic Phenomena: Temperature Wave Propagation

\[ \dot{v}(t) \]

\[ L \]

\[ T_{in} \quad t_{in} \]

\[ T_{out} \quad t_{out} \]
Delay Time Present

- Temperature wave propagates along pipeline with a significant delay at the consumer

- Heat Losses/temperatures are functions of time t and x position on pipeline – dynamic pipe models necessary to calculate!
Time Delay at furthest consumer
Case Study Results – Time Delay Tracking
Aggregation depth of 98% to furthest consumer

Approx 35 minute underestimation of delay time during steady state conditions
Reduction in Simulation Time for different depths of aggregation

- Simulation time reduced to approx. 0.01% of the original network simulation when aggregated from 146 down to 2 consumers.
Summary of results

- Both Danish and German Methods are effective at preserving dynamic mass flow and heat flow rates with the Danish method giving the best representation of the original network.

- Both aggregated network significantly **underestimate time delays** from the original the network – error can be expected to be higher for larger networks. Can be improved by through further tweaking of pipe parameters.

- Despite discrepancies in delay time conservation, simulation time could be reduced down to 0.01% of the original time at 98% aggregation of the consumers.
The next big challenge!

Network aggregation methods are highly limited when considering networks with multiple production sites – can only be performed when we assume flow directions in pipelines are constant.
Thank you for your Attention