The Gas Network Control Problem and How to Approach It

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Combinatorial Optimization @ Work 2020

The Gas Network Control Problem

General description

- Optimization of short-term transient gas network control of large real-world networks
- “Navigation system” (NAVI) for gas network operators

Source: Open Grid Europe

Problem

Given

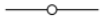
- Network topology
- Initial network state
- Short-term supply/demand forecast, e.g., 12–24 hours

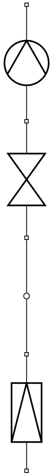
Goal

- Control each element s.t. the network is operated “best”
- Good control means: Fulfill demands as best as possible and change the control as little as possible

How to operate a gas network [in theory]

General Properties

- Network is represented as directed graph, arcs are single elements, nodes are junctions
- Main part of the network consists of pipes (icon: )



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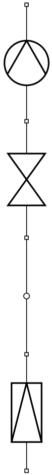
- Gas flows from high pressure to low pressure
- Gas is compressible, network acts like a storage



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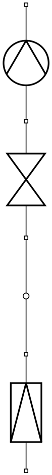
- Basic operations using special elements:
  - Connect or disconnect certain parts of the network to route the flow using valves (icon:)
  - Increase the pressure at certain points in the network using compressors (icon:)
  - Decrease the pressure at certain points in the network using regulators (icon:)
  - Note: Compressors and regulators can also act like a valve



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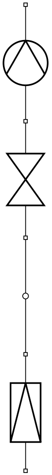
- Time is represented as a discrete set of future time points



Pipe

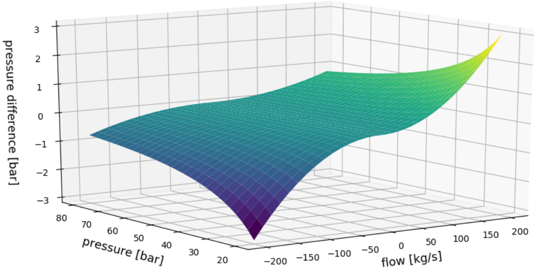
Gas flow in a pipe (ℓ, r) between times t_0 and t_1 can be described by the Euler Equations

$$p_{\ell,t_1} + p_{r,t_1} - p_{\ell,t_0} - p_{r,t_0} + \frac{2\,R_s\,T\,z\,\Delta_t}{L\,A}\left(q_{r,t_1} - q_{\ell,t_1}\right) = 0$$

Friction Dominated:

$$\frac{\lambda\,R_s\,T\,z\,L}{4\,A^2\,D}\left(\frac{|q_{\ell,t}|\,q_{\ell,t}}{p_{\ell,t}} + \frac{|q_{r,t}|\,q_{r,t}}{p_{r,t}}\right) + \frac{g\,s\,L}{2\,R_s\,T\,z}\left(p_{\ell,t} + p_{r,t}\right) + p_{r,t} - p_{\ell,t} = 0$$

https://commons.wikimedia.org/wiki/File:EuropipeII.jpg (CC BY-SA 3.0)



Valve and Regulator

Valve

- Open: $p_\ell = p_r$
- Closed: $q = 0$

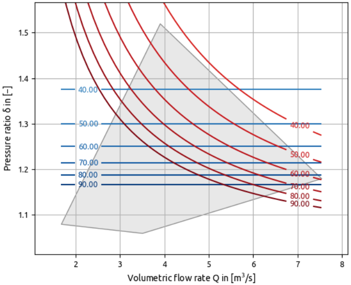
Regulator

- Valve that can partially open and thereby reduce the pressure
- Sometime refered to as Control Valve
- Has the two modes of the valve
- In addition there is the active mode with

$$p_\ell \geq p_r$$
$$q \geq 0$$

Compressor Unit

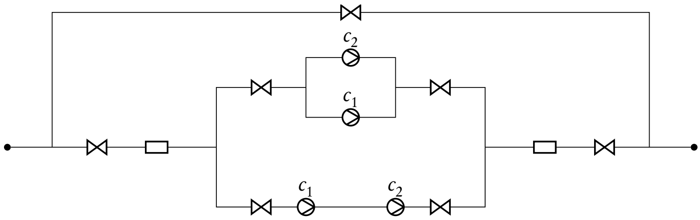
- Combination of a compressor and a drive for the necessary power



$$\eta P = q R_s T z \frac{\kappa}{\kappa - 1}\left[\left(\frac{p_r}{p_\ell}\right)^{\frac{\kappa-1}{\kappa}} - 1\right]$$

Compressor Station

- The actual network element
- Combines compressor units in parallel (more flow) and/or serial (larger pressure)



Meta Element: Network Station

- Network stations are subnetwork containing the majority of active elements in the whole network
- Most transport pipeline intersection areas are network stations

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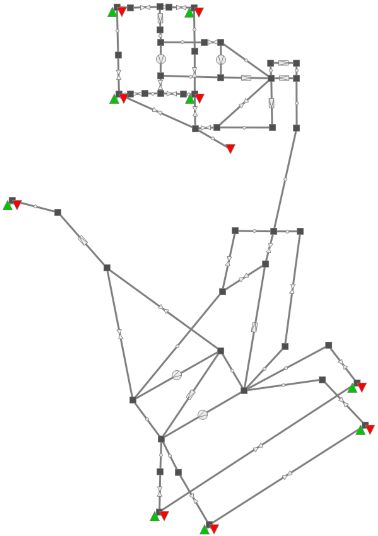
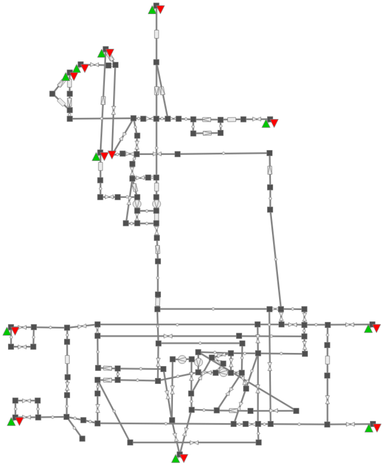
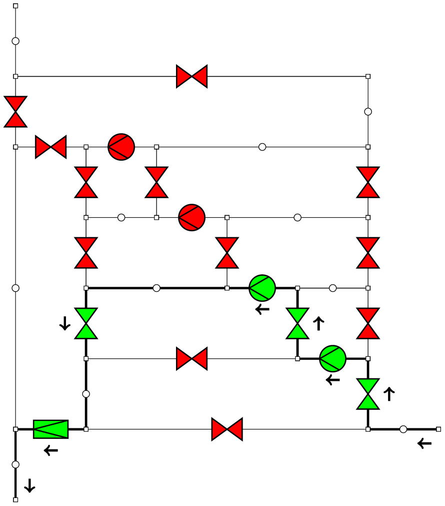
Example Network Stations





Network Station Operation Modes

- An operation mode is a valid combination of the single element modes in a network station
- Each network station has a known set of operation modes



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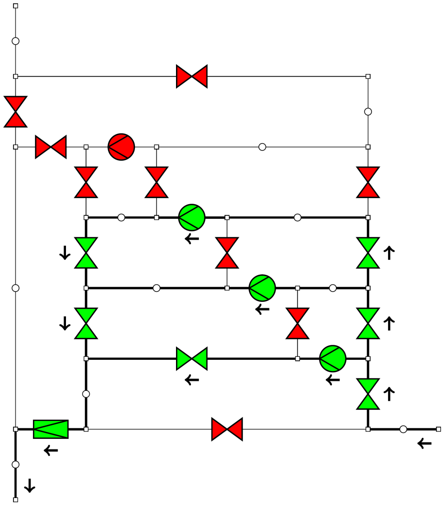

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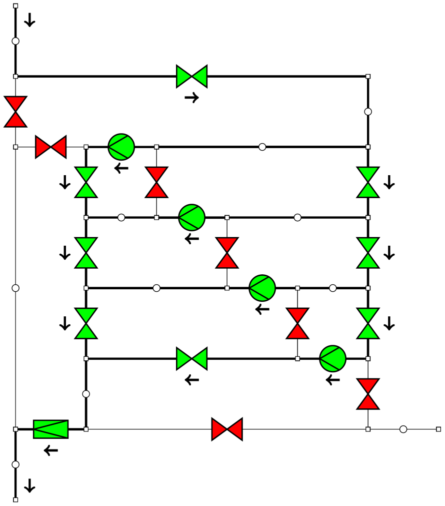

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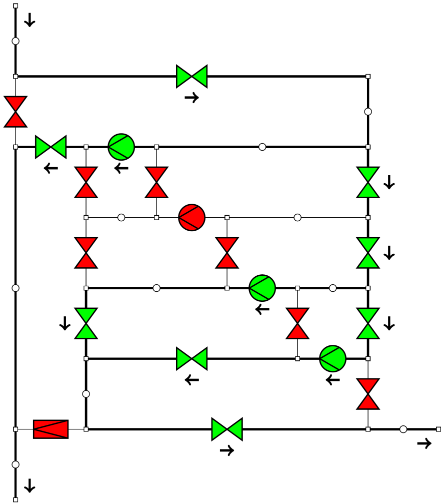

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  - There are a lot of not controllable element, which just cause some friction
    - Metering stations, gas coolers, gas heaters, ...
    - We replace those by artificial "resistors", causing a pressure loss in flow direction.
    - Modeled by the Darcy-Weisbach formula with drag factor ζ (similar to friction on pipes):

$$p_{\text{in}} - p_{\text{out}} = \frac{\zeta\, R_s\, T\, z}{2A^2}\left(\frac{q^2}{p_{\text{in}}}\right)$$

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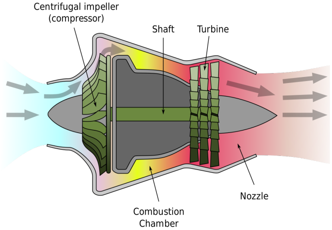
  - Single elements with unique behavior
    - Piston Compressor instead of Turbo Compressor
    - Compander
    - Integral Regulator Module

Turbo Compressor



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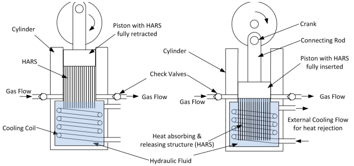
Piston Compressor



https://commons.wikimedia.org/wiki/File:Crowley_isothermal_compressor.jpg (CC BY-SA 4.0)

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  - Network areas with special behavior
    - "Breathing Bag" ("Atmender Sack") –
      An area of the network used for calibration of new network elements
    - "Gatherer" ("Sammler") –
      A set of different elements in one network station, which have to be operated at the same pressure level

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- Extensions of the standard models
  - Regulators and Compressor Stations use a target-value/set-point control
  - The drives powering the compressor run often based on gas from the network itself. The consumption is not measured and therefore unknown.
  - Future demands are contract-based and therefore to a certain degree flexible

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- Extensions of the standard models
- The network changes constantly
  - elements out of order
  - general maintenance
  - newly built network parts
  - mobile compressor, see `https://oge.net/en/for-customers/services/technical-services/network-products/mobile-compressors`

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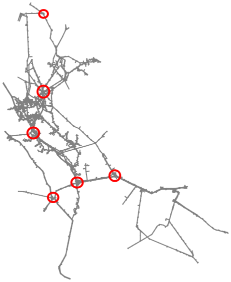

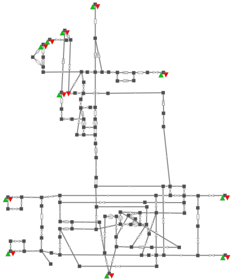

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- Start simple, small, and fast
  - Try to setup a model for a (very) simplified version of the problem
  - Use a small instance of the problem, which solves fast
  - Try to use real-world data from the start!

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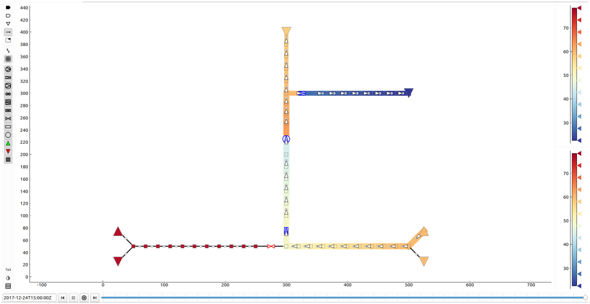

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  - Moving target
  - Early results may be underwhelming

The Last Slide

Thanks for watching!

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