Validation of thermal– hydraulic loss calculation in CEA network model

Reason to model network in cea:

* Easier to convert geo-data (.shp) into network models through python as compare to Simulink.
* One requires license to use Simulink.
* The network model is used for:
  + Plant sizing
  + Pump sizing
  + Calculate thermal loss in network
  + Calculate hydraulic loss in network

Validation Method:

* Compare the simulated results from the CEA network model against the identical thermal network model using Simulink Thermal Liquid Library.
* The networks in CEA and Simulink have identical layout, demands at substations (flow rate), pipe properties and plant supply temperatures, and the thermal and hydraulic losses are simulated in both models.
* Three test cases are developed in both cea and simulink:

|  |  |  |
| --- | --- | --- |
| Network 1 | Network 2 | Network 3 |
| C:\reference-case-open-network\baseline\inputs\network\network catalog\network1\network1.png | C:\reference-case-open-network\baseline\inputs\network\network catalog\network2\network2.png | C:\reference-case-open-network\baseline\inputs\network\network catalog\network3\network3.png |
| Parameters (input to simulink) | | |
| Pipe Insulation thermal conductivity | 0.023 [W/mK] |  |
| Soil thermal conductivity | 1.6 [W/mK] |  |
| Pipe roughness | 2e-5 | Steel pipe |
| Pipe length | 125 [m] |  |
| Pipe diameter | m | From cea network |
| Pipe insulation thickness |  | From cea network |
| Plant supply temperatures | C | Hourly data from cea |
| Substation flow rate | kg/s | Hourly data from cea demand |
|  |  |  |
| Outputs |  |  |
| Flow rate in each pipe | kg/s | on the supply side |
| Total pressure loss | Pa | on the supply side |
| Total heat loss | kW | on the supply side |

Results:

* Network1
* Network2
* Network3

|  |  |  |  |
| --- | --- | --- | --- |
|  | CEA model | Simulink model | Notes |
| Annual heat supplied by the heating plant | 2350 MWh/yr |  |  |
| Annual heating demand | 2303 MWh/yr |  |  |
| Plant size | 2.4 MWh |  | Max plant heat requirement (t=419) |
| Thermal loss @ t=419 (max) | 11.2 kWh | 10.4 kWh | diff = 0.4% |
| Annual thermal loss | 30 MWh/yr | 27 MWh/yr | diff = 11 % |
| Max pressure loss | 653 kPa (t = 419) | 662 kPa (t = 418) | diff = - 1% |
| Annual pressure loss | 185 MPa | 187 MPa | diff = - 1% |
|  |  |  |  |
| % thermal loss/ total heat supplied by the plant | * 1. % |  |  |
| Average difference in thermal loss | 7 % higher |  | Excluding t=438, 8667 |
| Average difference in pressure loss | 2 % lower |  | Excluding t= 438, 8667 |
| Hours with | | | |
| t = 438 | 0.1% of the maximum flow rate | |  |
| t = 8667 | 0.01% of the maximum flow rate | |  |

* + The plant capacity is sized at the maximum heat requirement, which include the heating demand from buildings and the thermal loss. At the time step with the maximum heating demand, the thermal loss is only 0.4% difference between CEA and Simulink.
  + The differences in total thermal losses between cea and Simulink over 8760 hours is around 3 MWh, which corresponds to 10% of annual heat loss. Since the total thermal losses over 8760 hours at the supply network accounts for 1.3 % of the total heat supplied by the heating plant. The 10% difference in the thermal loss calculation is in an acceptable range.
  + There are two instances (t=438, 8667) which the thermal/ hydraulic losses deviate more than 15% between the results from CEA and Simulink. This is because we assume all flows are turbulent flows in CEA, while Simulink considers different heat transfer resistances with different flow regimes (laminar, turbulent, and transitional).
  + Possible improvements:
    - To improve the heat transfer calculation at laminar and transitional flow regime.
    - Or implement a control strategy to terminate operation when flow rate is too low.

Conclusion:

* The simulation output from CEA network model is able to:
  + Decide the plant capacity (with 0.4% difference from Simulink)
  + Calculate thermal loss (with 10% difference from Simulink, which is equivalent to 0.1% of the total heat supplied in the network)
  + Calculate pressure loss (with 1% difference from Simulink)

Access to the Simulink models and example network shape files:

* CEAforArcGIS/validation/thermal\_network\_matrix