ESPr Heat Network / District Heating Models (v.0 22/3/19)

New Components

A number of new components have been developed for heat network simulation. The Relative Flow components (CMP 139 and 140) are also suitable for any system with multiple branches or supply nodes in series (e.g. domestic wet central heating system to multiple rooms (see exemplar 3BR-highres-plant)).

Heat or Cooling Load (with Temperature Limit) – CMP134 – 1-node component that adds or extracts heat from the water flow to replicate a heat interface unit. Outlet temperature can be limited for heating case to mimic heat exchanger limitations. Any residual heating shortfall is recorded and added to the demand at the next timestep. The residual output (third additional output factor) should be checked to confirm the system can meet demand. Heat source maximum output, system flow capacity and/or the node RFF factor can be modified to reduce any shortfall to approaching zero.

Shell Boiler – CMP135 – For heat networks a large boiler model with a temperature-maintained water volume is required. A full thermal model is included incorporating heat loss from an equivalent insulated cylinder of the same volume and surface area. The model has 3 nodes (boiler shell, stored water and outlet water). The model allows the temperature of the stored water to be controlled.

Buried Dual Insulated Pipe – CMP136 – 4-node (insulation, pipe, water in contact, water out) individual pipe module with a thermal link to an adjacent supply/return pipe buried in the same trench. Similar to the existing 'Primitive Parts' pipe module in basic functionality. Component code for adjacent pipe needs to be manually entered into plant configuration file.

Massless Converging Junction – CMP137 – 1-node simple flow combination component with no thermal interaction for use in large-scale systems where defining the physical properties is difficult.

Flow Balancing Junction – CMP138 – Heat networks are typically characterised by a separate generation and distribution flow loop separated by a heat store or bypass. This allows for different recirculating flows in each loop to aid balancing. Within the plant model this is represented by a component which determines the controlled flow in each loop and passes the difference through the bypass or store, with the direction appropriate to the relative flow per loop. Component allows for flow in both directions, acting as either a diverting or converging junction.

Diverter Valve (Relative Flow basis – see below) – CMP139 – 3-node component for diverting a controlled flow from a main pipe to a demand node. In contrast to the standard 3-node diverter valve component (CMPXXX), the controlled variable is not an independent proportional flow split but a control factor with a maximum range proportional to the flow capacity of the demand node relative to the others. New code elements ensure that each junction has visibility of all downstream junctions ensuring the flow splits at each junction are both proportional to relative demand and consistent with the overall flow balance of the system. This is designed to replicate in the plant environment normal pressure balancing of flows across all demand nodes.

Flow Junction (Relative Flow basis – see below) – CMP140 – 3-node component to divert flow at a manual (uncontrolled) junction using the same relative flow logic as CMP139. New code logic ensures that at each junction the total relative flow control factors to each downstream demand node are known and used to set the proportional flow split at the manual junction.

Massless Diverter Junction – CMP141 – 2-node simple controlled flow diverter component with no thermal interaction for use in large-scale systems.

2-port Stratified Tank (Bypass) – stratified_tank_bypass – Modified version of the standard stratified tank for 2-port systems located between the supply and return flows of a heat network. Tank is supplied via a CMP138 component located at the top and bottom of the tank, which allows for flow in both directions depending on the flow balance between the generation and supply circuits.

(CHP models are under review for incorporation in the DH model framework)

Heat Demand

Each connection within the heat network is modelled with a diverter valve (CMP140), inlet insulated pipe, demand load (CMP134), outlet insulated pipe and converging junction (CMP137) to the return network. The demand load component is a simplistic device that extracts heat from the water flow. (More complex representations incorporating a heat exchanger and building side components are being investigated). The outlet temperature from the load is limited to a fixed value to mimic heat exchanger approach temperature operation.

Cumulative unmet demand per timestep due to the temperature limitation is recorded and added to the demand requirement at the next timestep. The residual output (third additional output factor) should be checked to confirm the system can meet demand. A warning is given at each timestep this occurs. Heat source maximum output, system flow capacity and/or the node RFF factor can be modified to reduce any shortfall to approaching zero. Short duration shortfalls at the start of a heat demand period that are recovered from quickliy can be ignored as the system will take some timesteps to react to an increased demand.

The demand load per timestep is set via a boundary file (referenced from the cfg file (Load.bcd in the DH1 exemplar)) and a control loop that reads the appropriate column in the boundary file (2nd digit on 3rd row) to set the load. The bcd file should contain one row of data per model timestep. If the number of timesteps exceeds the bcd file row data the model will restart from the top of the bcd data. The maximum load is set within the control loop (first data item in W, minus for a heat load) and the boundary file the proportion of this maximum load per timestep.

```
* Control loops   12
# reads measurements from a boundry data file.
   -5    1    0    0    0  # sensor
# plant component  42:Loadx1 @ node no.  1
   -1   42    1    0  # actuator
    1  # all daytypes
    1  365  # valid Sat-01-Jan - Sun-31-Dec
     1  # No. of periods in day: weekday
   16    3   0.000  # ctl type, law (Prop numerical ctrl.), start @
      5.  # No. of data items
  -20000.00000 0.00000 1.00000 0.00000 0.00000
```

Relative Flow Control (RFC)

Plant-based heat networks with multiple headers and demand nodes (e.g. domestic central heating, district heating) requires a method to ensure the proportion of the flow supplied to each header and node are accurate based on the relative capacity and control action at each node. The existing diverter valve component has no visibility on the capacity or current status of any downstream nodes relative to its demand, leading to unstable and unrealistic results. An alternative approach has been developed that allows the flow to each node to be determined based on the node control action relative to all node control actions.

This is achieved by assigning each demand node a maximum Relative Flow Factor (RFF) which reflects the flow capacity of this node relative to all other nodes. The most realistic basis for the RFF would be the node pipe cross-sectional area, which would be linked to the size of the control valve or pump in a real circuit. Alternatively, the maximum demand (e.g. radiator or Heat Interface Unit sizing) can be used as a proxy. The baseline value for the RFF is unimportant as long as the relative value for each node is consistent. The RFF is set via a control loop as the maximum control output linked to the outlet flow temperature from the node. RFC mimics actual pressure-driven operation of inlet control valves to demands by determining effectively how far the valves are open and allocating total system flow proportionally.

An example control loop for a diverter valve is shown below. The RFF for this junction is 3.0 (the second digit in the bottom row of data items).

```
* Control loops    6
# senses var in compt. 24:pipeL22 @ node no.  3
   -1   24    3    0    0  # sensor
# plant component  21:DivV2 @ node no.  1
   -1   21    1    0  # actuator
    1  # all daytypes
    1  365  # valid Sat-01-Jan - Sun-31-Dec
     1  # No. of periods in day: weekday
   18    5   0.000  # ctl type, law (Prop`l damper ctl.), start @
      6.  # No. of data items
  0.00000 3.00000 85.00000 65.00000 0.00000 0.00000
```

The RFC process requires that plant section before and after a flow split is given a node number (see red numbering on DH1.gif). These node numbers are referenced in the plant configuration file as outlined below. The number ordering is not important as long as it is consistent with the model structure.

Two types of RFC component is currently available, a diverter valve, where the flow is controlled for one of the two outlet nodes, this is typically a node feeding a demand, and a flow splitter, which splits the flow based on the relative demands from each downstream branch. Specific examples are shown below:

- *Diverter valve with further downstream demand nodes (i.e DivV1 in DH1 exemplar):*
  Inlet (component node 1) and 2nd outlet node (component node 3) identified and bypass RFF nominally set to zero as it is ignored in this case:

```
#->  xx, 3-node Diverter Valve - Relative Flow
 DivVx            123
   1        # Component has   1 control variable(s).
  0.00000000
   3
      4.0000     #   1 Outlet 2 RFF Node
      2.0000     #   2 Inlet RFF Node
      0.0000     #   3 Bypass RFF
```

- *Diverter valve with no further downstream demand nodes and supply-return bypass piping (i.e DivV2 in DH1 exemplar):*
  Inlet node identified, outlet node set to 99 to identify bypass, and fixed RFF of bypass pipework set to determine proportion of flow to bypass:

```
#->  xx, 3-node Diverter Valve - Relative Flow
  DivVx            123
    1        # Component has   1 control variable(s).
   1.00000000
    3
       99.000     #   1 Outlet 2 RFF Node
       4.0000     #   2 Inlet RFF Node
     0.50000E-02 #   3 Bypass RFF
```

- *Diverter valve with no further downstream demand nodes or bypass (i.e. a 2-port control valve) (i.e DV4 in 3BR_highres_plant exemplar):*
  Inlet node identified, outlet node set to 99 to identify no further downstream nodes, and a zero RFF set to indicate no further downstream flow. ESPr will give a warning that the third node of this diverter has no exit connection but this can be ignored :

```
#->  xx, 3-node Water 3-port Diverter Valve - Relative Flow
  DivVx            123
    1        # Component has   1 control variable(s).
   1.00000000
    3
       99.000     #   1 Outlet 2 RFF Node
       4.0000     #   2 Inlet RFF Node
       0.0000     #   3 Bypass RFF
```

- *Flow splitter to two main branches (i.e. SP1 in DH1 exemplar):*
  Inlet and both outlet RFF node numbers identifed. RFF factor nominally set to zero as it is ignored.

```
#->  xx, 3-node Diverter Junction - Relative Flow
  SPx              122
    0        # Component has   0 control variable(s).
    4
       2.0000     #   1 Outlet 1 RFF Node
       3.0000     #   2 Outlet 2 RFF Node
       1.0000     #   3 Inlet RFF Node
       0.0000     #   4 Relative Flow Factor (RFF)
```

- *Flow splitter to a demand node (i.e. 'always-on' node with no flow control) (i.e. SP1 in 3BR_highres_plant exemplar):*
  Inlet and 2nd outlet RFF node number (component node 3) identified. Demand node (component node 2) RFF node number set to 999 to identify this as a demand node. RFF factor for this demand node set (ignored unless Outlet 1 is set to 999).

```
#->  xx, 3-node Diverter Junction - Relative Flow
  SPx              122
    0        # Component has   0 control variable(s).
    4
       999.00     #   1 Outlet 1 RFF Node
       4.0000     #   2 Outlet 2 RFF Node
       2.0000     #   3 Inlet RFF Node
       1.0000     #   4 Relative Flow Factor (RFF)
```

The RFC method requires that the call to the CMP_XXXC file in pmatrx.f is done in a particular order to ensure that each RFC connection has visibility of the total relative flow value for all downstream connections. This is done via a new subroutine (SRFCSEQ) in pltcfg.f, that identifies all flow splitters and diverter valves, and their inlet and outlet node values, and orders them appropriately. No other elements of the plant matrix calculation process is impacted by this order change. This also ensures that the order of the components in the plant configuration file is not important.

Exemplar Models

DH1 - Base-No Store

This is a simple exemplar designed to introduce the generation and supply side component options and a simple single circuit control for basic assessments of system requirements. This model incorporates all main components for a single circuit heat network without heat store.

Generation: Two shell boilers are included with both controlled to maintain a temperature of 85degC in the water volume. Flow from the single pump is set to maintain a return temperature of 65degC. Flow to the second boiler is controlled based on the temperature in the supply circuit.

Supply: On the supply side there are three supply nodes. Two loads on one branch and one on another. The model therefore incorporates both types of 'relative flow' component: a uncontrolled diverter junction; and controlled diverter to a supply node.

More exemplars are under development.