1. Document History

Date	Version	Description	Author
2021-11-19	1.0	controller specification according to the final implemented benchmark setup	Edmund Widl (AIT)

2. Functional Description

Background:

System configuration `MENB-SC` specifies a thermal network, including the so-called flex heat controller, see Figure 1. The system comprises two (aggregated) consumers, a power-to-heat facility consisting of a heat pump and storage tank as well as a simplified thermal distribution network. The thermal network is connected to an external heating grid.

This specific setup is typical for a local energy community (specifically a renewable local energy community) and, as such, allows to address the issue of exploiting local electrical power generation from renewable energy resources for the decarbonization of the heat supply. Due to the intermittent nature of the local electric power generation, the heat pump cannot be used directly to operate the thermal network in islanded mode. Instead, the heat pump feeds a storage tank, which can be discharged to support the operation of the thermal network. This approach requires a coordination of the local electric power generation with the operation of the heat pump and the storage tank.

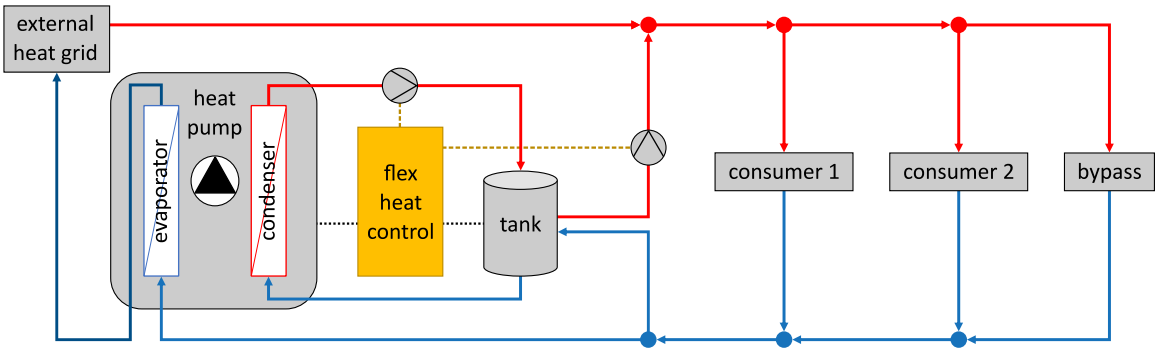

Figure 1: Thermal sub-system including the flex heat controller

Problem formulation:

To support the operation of thermal network, the mass flow fed from the storage tank to the network's supply line must be within an acceptable temperature range. At the same time, the operation of the heat pump is limited by the power consumption rate setpoint from the voltage controller. This requires a coordination of heat generation, heat storage and network support in the power-to-heat facility.

Controller scope:

The flex heat controller decides whether the heat supply is covered entirely through the external grid or whether the power-to-heat facility supports by discharging the tank. The temperature of the storage tank is monitored and kept within acceptable limits. If required, the heat pump is used to charge the tank, taking into account the power consumption setpoint from the voltage controller (i.e., the power consumption never exceeds the setpoint, but may be less).

The flex heat controller specified in this document governs the operation of the power-to-heat facility by actuating hydraulic pumps in two separate loops:

- hydraulic pump `pump_cond` controls the mass flow in the condenser loop, where cold water is drawn from the bottom of the storage tank, heated up in the heat pump's condenser and fed back at the top of the tank.
- hydraulic pump `pump_tank` controls the mass flow in the network support loop, where hot water is fed from the storage tank to the supply line (and simultaneously an equal amount of cold water is drawn from the heating network's return line to refill the tank).

3. Terminology

Local energy community	Local energy communities (LEC) are a way to organize collective energy actions around open, democratic participation and governance and the provision of benefits for the members or the local community (Roberts et al., 2019).
Renewable local energy community	A special type of LEC that incorporate renewable energy sources, renewable local energy communities can be active in all energy sectors and involve activities in production, consumption and selling of renewable energy.

4. Methodology

Thermal system operational modes

From the perspective of the thermal network, the following operational modes can be supported through the flex heat controller:

- *Mode 1*: network supplies, heat pump and hot water tank inactive
- *Mode 2*: network supplies, heat pump charges the hot water tank
- *Mode 3*: hot water tank supplies, heat pump off
- *Mode 4*: hot water tank supplies, heat pump on
- *Mode 5*: network supplies, hot water tank supports, heat pump off
- *Mode 6*: network supplies, hot water tank supports, heat pump on

Based on the measurement of the storage tank temperature and the power consumption setpoint for the heat pump (coming from the voltage controller), the flex heat controller can switch between these modes. The switching between modes follows a simple set of rules, represented by a state machine where each state corresponds to a specific operational mode. Figure 2 shows a graphical representation of the flex heat controller's state machine.

Heat pump operation

The mass flow through the condenser loop determines the electrical power consumption of the heat pump. Therefore, the operation of `pump_cond` is governed by a PID controller, see Figure 3. The setpoint for this PID controller is determined by the state machine, whose definition effectively implements a hysteresis controller for charging the tank:

- *Mode 1*, *Mode 3* and *Mode 5*: hydraulic pump `pump_cond` is switched off (PID output set to zero, resulting in zero mass flow rate) regardless of the voltage controller setpoint

- *Mode 2*, *Mode 4* and *Mode 6*: the voltage controller's power consumption setpoint is used as setpoint for the PID controller of hydraulic pump `pump_tank`.

Thermal storage operation

The mass flow through the network support loop determines the heat supply to the thermal network. To keep the storage tank temperature within acceptable limits, the definition of the state machine effectively implements a hysteresis controller for discharging the tank:

- *Mode 1* and *Mode 2*: hydraulic pump `pump_tank` is switched off (zero mass flow rate)
- *Mode 3*, *Mode 4*, *Mode 5* and *Mode 6*: hydraulic pump `pump_tank` is switched on with a constant mass flow rate

5. Limitations

In view of the limited capacity of the heat pump and the storage tank, the flex heat controller disregards *Mode 3* and *Mode 4*, where the thermal system would operate in islanded mode. Hence, the corresponding modes are not included into the state machine representation in Figure 2.

6. Inputs

Name	`meas_tank_temp`
Type	MeasureConnection
Unit	°C
Range	(0, 100)
Expected update rate	1-15 min (simulation step size)
Description	measurement of the storage tank temperature

Name	`meas_hp_p_el`
Type	MeasureConnection
Unit	kW_{el}
Range	[0, 100]
Expected update rate	1-15 min (simulation step size)
Description	measurement of electrical power consumption of heat pump

Name	`setpoint_hp_p_el`
Type	CtrlConnection
Unit	MW_{el}
Range	[0, 0.15]
Expected update rate	1-15 min (simulation step size)
Description	setpoint for power consumption of heat pump from voltage controller

7. Outputs

Name	setpoint_tank_mflow
Type	CtrlConnection
Unit	kg/s
Range	[0, 10]
Expected update rate	1-15 min (simulation step size)
Description	setpoint for tank discharge mass flow

Name	setpoint_cond_mflow
Type	CtrlConnection
Unit	kg/s
Range	[0, 10]
Expected update rate	1-15 min (simulation step size)
Description	setpoint for heat pump condenser mass flow

8. Use Cases

Use Case Example	Heat pump operation
Date created	2021-11-19
Actor	• flex heat controller • voltage controller • storage tank • hydraulic pump pump_cond
Description	The flex heat controller governs the mass flow through the heat pump's condenser loop through the operation of hydraulic pump pump_cond. With the help of a PID controller (see Figure 2) the mass flow of the hydraulic pump is regulated.
Preconditions	• The power consumption setpoint from the voltage controller is not zero. • The temperature of the storage tank is below its maximum allowed value.
Postconditions	The flex heat controller operates either in *Mode 2* or *Mode 6*.
Priority	medium
Frequency of use	periodically (according to simulation step size)
Normal course	The mass flow through hydraulic pump pump_cond is regulated using the heat pump's power consumption as process variable and a setpoint determined by the flex heat controller's state machine (see Figure 3).
Alternative course	In case the power consumption setpoint from the voltage controller is set to zero or the temperature of the storage tank reaches its maximum allowed

	temperature, hydraulic pump `pump_cond` is switched off (PID output set to zero, resulting in zero mass flow rate) and the flex heat controller transitions to *Mode 5*.
Exceptions	N/A
Assumptions	N/A
Notes and Issues	N/A

Use Case Example	Thermal storage operation
Date created	2021-11-19
Actor	• flex heat controller • storage tank • hydraulic pump `pump_tank`
Description	The flex heat controller supports the operation of the thermal network by feeding hot water from the storage tank to the supply line.
Preconditions	The temperature of the storage tank is above its minimum allowed value.
Postconditions	The flex heat controller operates either in *Mode 5* or *Mode 6*.
Priority	medium
Frequency of use	periodically (according to simulation step size)
Normal course	The flex heat controller operates hydraulic pump `pump_tank` with a constant mass flow rate until the temperature of the storage tank reaches its minimum allowed value.
Alternative course	In case the minimum allowed temperature of the storage tank is reached, hydraulic pump `pump_tank` is switched off (zero mass flow rate) and the flex heat controller transitions to *Mode 2*.
Exceptions	N/A
Assumptions	N/A
Notes and Issues	N/A

9. Diagrams (data flow diagrams, sequence diagrams, logic diagrams, state diagrams, control hierarchy, etc.)

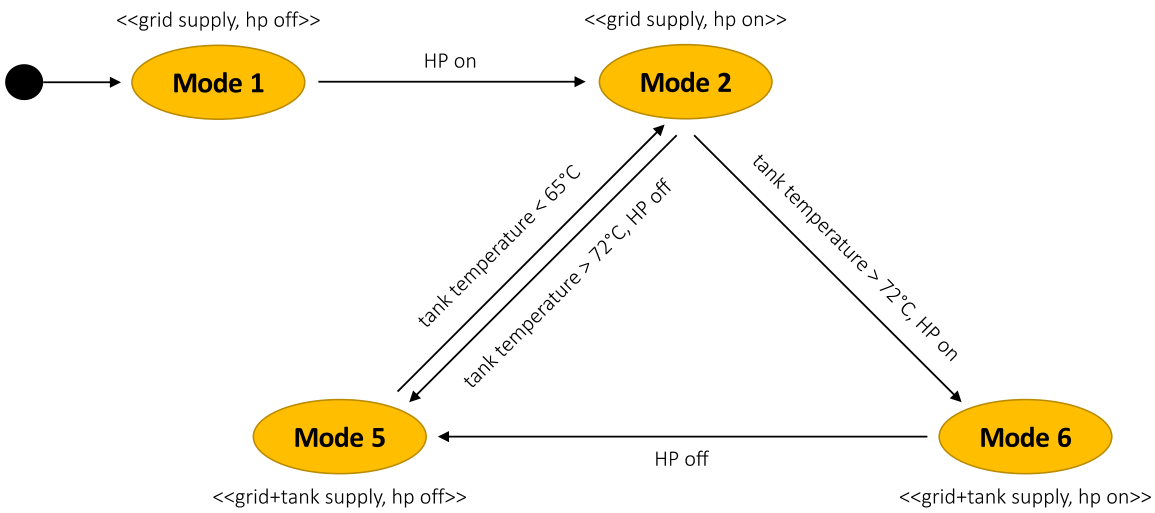

Figure 2: State machine representation of the operational modes implemented by the flex heat controller

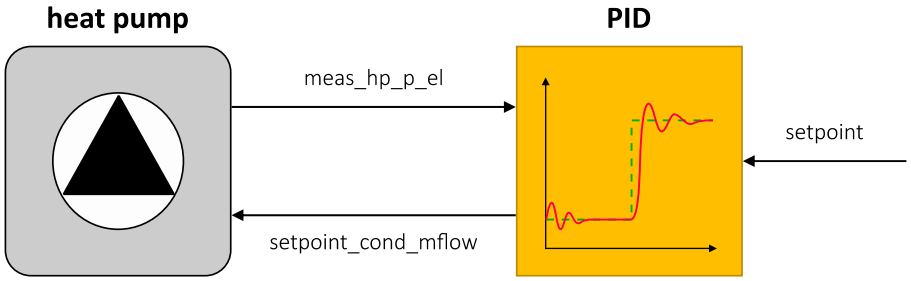

Figure 3: PID control setup for regulating the heat pump's power consumption.

10. Algorithms (pseudocode)

N/A

11. Embedding (implicit functions or algorithms)

N/A

12. Deterministic Functions

N/A

13. Stochastic Functions

N/A

14. References