sCO2-4-NPP: Innovative sCO2-Based Heat Removal Technology for an Increased Level of Safety of Nuclear Power Plants

Deliverable 5.6

Fast running version of the sCO_2 heat removal system for implementation in control logic of PWR simulator

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Type		
R	Document, report excluding the periodic and final reports	X
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	
Dissemination level		
PU	PUBLIC, fully open, e.g. web	X
CO	CONFIDENTIAL, restricted under conditions set out in Model Grant Agreement	

Revision History

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Table of Contents

List of Tables

List of Figures

1 List of Acronyms

Abbreviation / Acronym	Description / meaning
ATHLET	Analysis of THermalhydraulics of LEaks and Transients (system code of GRS)
CHX	Compact Heat Exchanger
ClaRaPlus	Component library in Modelica
CVR	Centrum výzkumu Řež
Dymola	Dynamic modelling laboratory, modelling and simulation environment This environment serves for modelling and simulation of the models written in Modelica language
EDF	Électricité de France SA, French utility
FMI	Functional mock-up interface
FMU	Functional mock-up unit
GfS	Gesellschaft für Simulatorschulung (company)
HEX	Heat exchanger
KSG	Kraftwerks-Simulator-Gesellschaft (company)
MODELICA	Standardized object-oriented modelling language
NPP	Nuclear Power Plant
SBO	Station Black Out
sCO_2	Supercritical carbon dioxide
TAC	Turbo Alternator Compressor
TS Media	Library in Modelica for thermodynamic properties
UHS	Ultimate Heat Sink
UJV	ÚJV Řež a.s.

2 Executive Summary

The content of this deliverable D5.6 is dedicated to the description of the FMU[1] version of the current Dymola sCO_2 loop model. This FMU version of the sCO_2 loop model shall be coupled by KSG with a PWR Konvoi full-scope simulator. It is supposed that such a coupled system will allow for a real time dynamic simulation and visualization of the station black out scenarios with possible operator intervention. The deliverable is primarily intended for the user of the FMU model (KSG) to facilitate implementation of the FMU model in the simulator.

The FMU version of the sCO_2 loop model comprises:

- TAC, CHX, UHS and interconnecting piping
- push-up start auxiliaries (partly)
- sCO_2 loop control logic
- water side of the CHX including temperature control
- I/O interface for the coupling with the Konvoi simulator

[1] FMU stands for Functional Mock-up Unit. It is a form of a Modelica model that follows the FMI standard. Dymola is capable of exporting and importing models in a form of FMU. Current sCO_2 loop Dymola FMU model uses FMI 2.0 version.

3 Introduction

The present report consists of three main parts. In chapter 4, the mechanical part of the sCO_2 loop is visualized and shortly described. In chapter 5, this description is expanded by control logic details. In chapter 6, the FMU input/output variables are listed, and recommendations are given with respect to their values where needed.

The current FMU version of the sCO_2 loop model prepared in Dymola has the following features:

- push-up starting auxiliaries partly included, the rest being replaced by the boundary conditions
    - ambient air temperatures below the critical temperature (31 °C) are not supported now for the starting period (CO_2 condensation). After the starting period finishes, ambient air temperature may be changed within the design limits (from +45 °C to -45 °C)
- transition from the starting period to the long-term decay heat removal period is modelled with the help of an auxiliary clutch. If this clutch is unlocked, the TAC speed evolves autonomously based on the pressure distribution controlled by CO_2 injection. If this clutch is locked, the TAC speed evolves according to turbine inlet temperature control
- long term decay heat removal capabilities are being achieved by the:
    - turbine inlet temperature control
        - TAC speed
    - compressor inlet temperature control
        - UHS fan speed
        - UHS bypassing
    - compressor inlet pressure control
        - CO_2 loop filling
        - CO_2 loop blow-off
- HEX version as modelled in deliverable D2.2
- sCO_2 loop arrangement in the NPP corresponds to the idea of placing the loop in the VVER 1000 environment (Temelin). Later, the FMU shall be updated to correspond the EPR layout prepared by EDF.

4 Mechanical part of the sCO_2 loop Dymola model

In this chapter, the description of the mechanical part of the sCO_2 loop model prepared in the Dymola environment will be given.

Figure 1 shows the Dymola model of the sCO_2 heat removal loop while Figure 2 shows a detailed picture of the push-up start accessories. In Figure 2, the push-up start accessories are shown in a red colour. Those elements that are modelled in Dymola are bounded by a dashed box. The abbreviation "BC" is placed where boundary conditions are being applied instead of a full modelling. The meaning and basic function of the individual components are described in Table 1. The operational range of one individual loop is approximately between 10 MW and 5.5 MW.

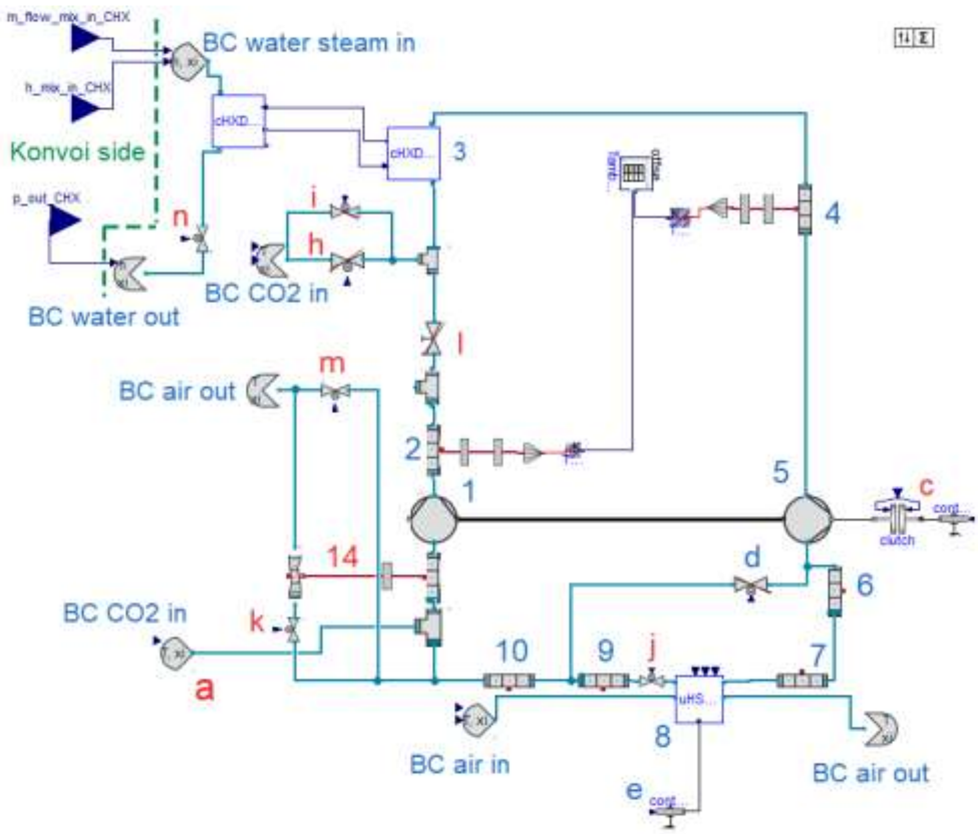

Figure 1: Scheme of the heat removal system in Dymola modelling environment

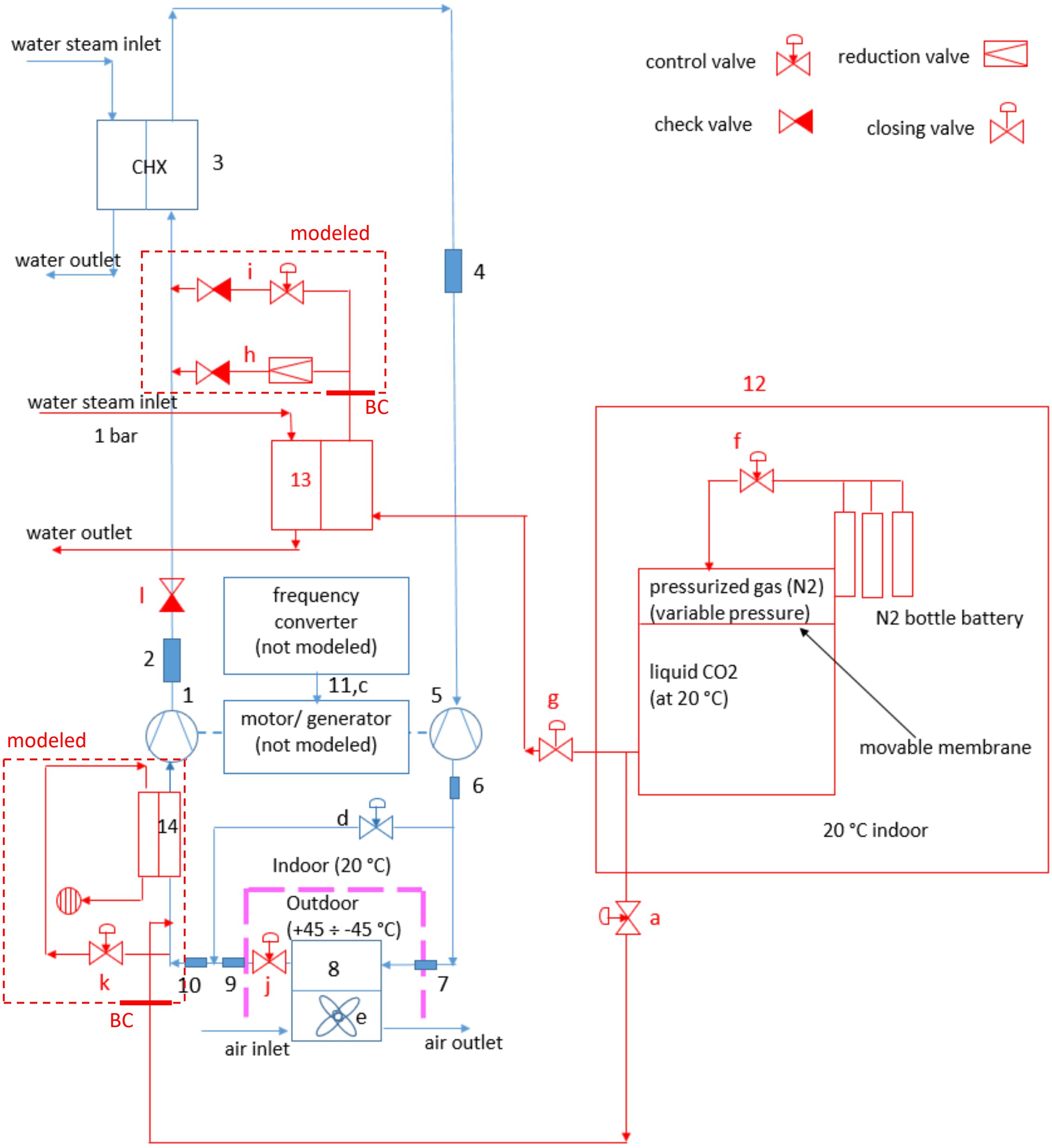

Figure 2: Push-up start accessories

Table 1: sCO_2 loop components with push-up start accessories

Symbol	Component	Note
1	Turbocompressor	Placed in a shelter (20 °C)
2	Interconnecting piping	The compressor outlet (ground level) is connected to the CHX (33 m above the ground). Mostly in the building (20 °C)
3	CHX (CO_2 and water side)	CHX is an interface for coupling of Dymola model and KSG Konvoi simulator. In the building (20 °C)
4	Interconnecting piping	Connects CHX with the turbine. Mostly in the building (20 °C)
5	Turbine	Placed in a shelter (20 °C)
6,7	Interconnecting piping	Modelled as if in the shelter (20 °C)
8	UHS	Outdoor
9,10	Interconnecting piping	Modelled as if in the shelter (20 °C)
11	Motor / generator with frequency converter	Serves for electricity production when power excess is available. This component has not been modelled yet and is replaced in Dymola model by speed source
12	CO_2 pressure source	Source consists of expansion tank with movable membrane, nitrogen bottle battery and accessories. High pressure nitrogen gas is injected above the membrane to keep CO_2 in a liquid state. Control valve “f” controls the pressure. This part is not modelled here, instead the boundary condition is placed in front of the valves “i” and “h” (Figure 1)
13	Starting CO_2 evaporator	In this heat exchanger, liquid CO_2 is being evaporated to enter the loop in a gaseous state. Not modelled in the current sCO_2 loop Dymola model
14	Starting CO_2 cooler	Decrease the CO_2 temperature at compressor inlet. Low temperature CO_2 after the expansion through the control valve “k” is used. Later, when the “k” valve is closed and there is enough power excess to drive the UHS fans, this cooler is no longer operated
a	Filling	Serves for changing the sCO_2 loop filling during the heat removal campaign.
b	Divider	This component is in use only when coupled simulation with Athlet VVER 1000 model is being performed. Not used in FMU sCO_2 loop Dymola model (not shown in the current figures)
c	TAC speed control	Serves for changing the sCO_2 loop CO_2 mass flow rate. The mechanical clutch component in the Dymola model is only auxiliary not real element.
d	UHS bypass valve	For low ambient air temperatures, this valve opens and bypasses the UHS.
e	Fan speed control	Fan speed controls the UHS thermal capabilities

Table 1 continuation

Symbol	Component	Note
f	Nitrogen control valve	Control nitrogen pressure above the movable membrane
g	Closing valve	Isolates starting line from the loop
h	Starting reduction valve	Opening this valve begins the sCO_2 loop start-up procedure. This valve is used to handle high pressure drops.
i	Starting control valve	Opens when the sCO_2 loop is partly filled
j	UHS outlet control valve	Valve serves during low ambient air temperatures start-ups.
k	Compressor inlet pressure control valve (for start only)	During start-up procedure controls the pressure at compressor inlet
l	Check valve at compressor outlet	Isolates high- and low-pressure part of the loop during the start up. When compressor overcome the starting pressure, this valve automatically opens
m	Compressor inlet pressure control valve (long term control)	Valve operates during the long-term decay heat removal campaign
n	CHX water outlet temperature control valve	Controls CHX water outlet temperature

In Table **2** the list of used modelling tools and their versions is summarized.

Table 2: Modelling instruments

Software	Version	Note
Dymola	2022x	Commercial modelling and simulation environment
Modelica Standard Library	4.0.0	Free Modelica library
ClaRaPlus	1.4.0	Commercial Modelica library
ClaRaPlus_CVR	1.3.5	Adopted ClaRaPlus library
TS Media	1.6.1	Commercial fluid properties Modelica library
FMI	2.0	Version of the FMI standard used for exporting the sCO_2 loop Dymola model

5 sCO_2 loop Dymola model control logic

In this chapter, the individual control logics are listed together with a description of their function. The figures also visualize the names of the input variables to be defined from the Konvoi simulator. In the next chapter, these inputs are tabulated together with their expected (or initial) values. Some controllers have their constants accessible from the outside of the model through the input connectors but some not. This might be changed in the future if necessary. Either on/off or PI controllers are used in the FMU model.

5.1 Starting (h,i) and compressor inlet pressure control (k) valves

Before SBO occurs, the sCO_2 loop is filled with CO_2 at slight overpressure and is in stand still conditions. After SBO occurs, the starting valves "h" and "i" (Figure 3) start to open in a prescribed manner from the outside of the FMU model. CO_2 from the tank (not modelled in the current model) starts to flow into the sCO_2 loop and causes the TAC to rotate autonomously.

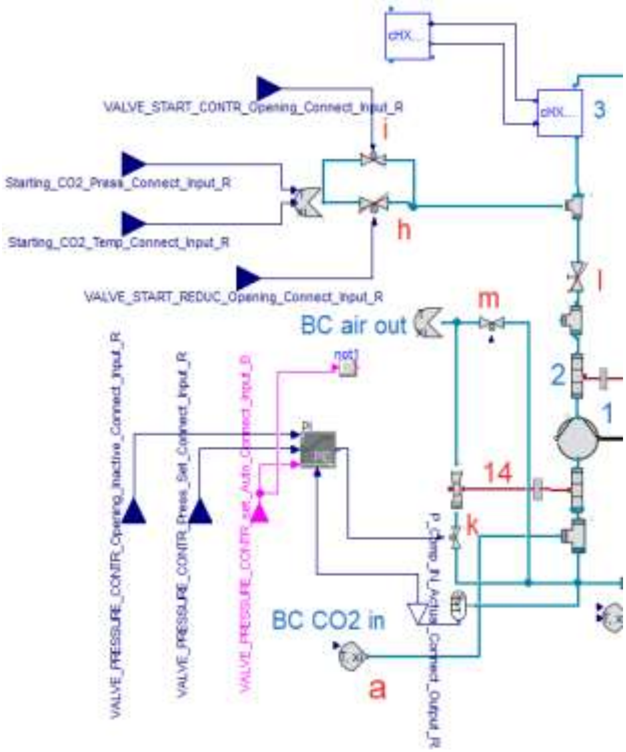

Figure 3: Starting and pressure control valves

Pressure in the loop continuously increases and after some period this pressure reaches 126 bara at the compressor inlet. At this moment compressor inlet pressure control valve "k" starts to open to keep the pressure near the set value (126 bara) defined through the input connector. If this "k" valve is opened, then the mass flow rate through the compressor is less than the mass flow rate through the turbine, making an opportunity for high power excess if the TAC shaft is "somehow" fixed (see chapter 5.2). If the "k" valve control is activated, then the "m" valve control is inactive ("not1" component) and vice versa. This is controlled with the help of the Boolean connector (in the figure marked in violet colour) accessible from the outside of the FMU.

5.2 TAC speed control

In the current Dymola sCO_2 loop model, there are two TAC speed control logics, each of which reflects a different sCO_2 loop operating mode (Figure 4). The part bordered by a red dashed line serves during the start-up and the part bordered by a full red line serves during the long-term decay heat removal operational mode.

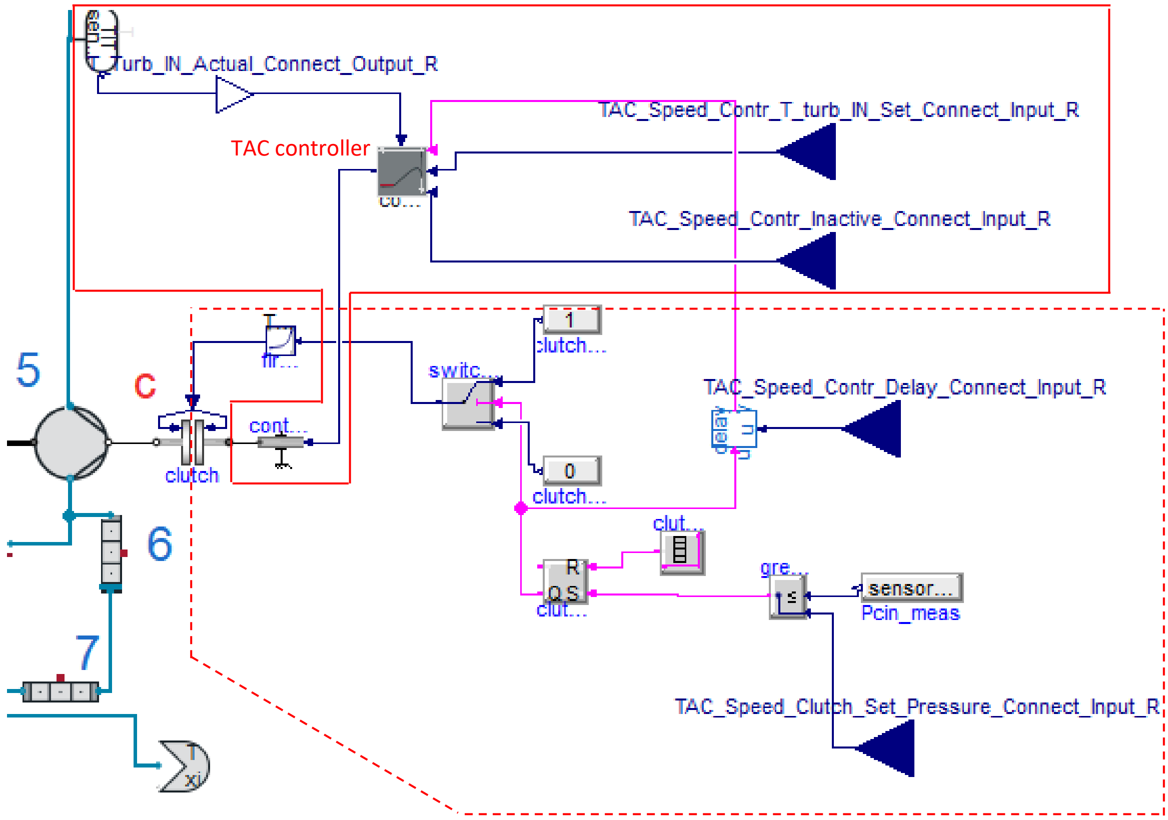

Figure 4: TAC speed control layout

5.2.1 TAC speed control during start-up period

This control logic is visualized in Figure 4 within the red dashed boundary. The purpose of this control logic is to switch the sCO_2 loop from the autonomous evolution defined by the starting valves opening to the controlled system behaviour defined by the different control logics as they are described here. The main parts of the TAC speed control logic dedicated to the starting period are clutch (c component), RS flip flop component, compressor inlet pressure sensor (Pcin_meas), switch, TAC controller. TAC controller is initially in manual mode which allows to set the controller output to a predefined value of speed rotation. As the clutch (the auxiliary component that is not present in reality[2]) is initially unlocked the turbine part of the clutch rotates autonomously with the TAC and the other part (let's call it controlled part) of the clutch rotates with the predefined speed. This is a disadvantage of the current model, because it would be better if the controlled part of the clutch monitored the speed of its counterpart before the clutch is locked. As described in chapter 5.1 the current model makes use of the difference between the compressor and turbine mass flow rates (valve "k" is opened) before the clutch is locked. So, the clutch is locked when the pressure at compressor suction is greater than some prescribed value that ensures that the valve "k" is already opened. At this moment RS flip flop sends true to Q output and the clutch is locked within a few seconds. This true signal also switches the TAC controller from manual mode to automatic after the delay time elapsed. This time delay is incorporated

[2] The clutch in the model replaces the electro/mechanical part of the motor/generator.

here to allow the system to settle after the clutch is locked. After the TAC controller is on, the TAC speed is accommodated to be in accordance with the prescribed turbine CO_2 inlet temperature.

5.2.2 TAC speed control during decay heat removal

After the clutch is locked and the delay time elapsed, the TAC long term speed control is switched on. This control logic is shown in Figure 4 within the full red line area. The difference between the set and measured turbine inlet temperature is transformed to the TAC speed change. In the current model, this PI controller does not have access to its constants from the FMU outside.

5.3 UHS fan speed and bypass control

UHS (8) fan speed (e) and UHS bypass (d) control keeps the compressor inlet temperature near the prescribed value (55 °C). In Figure 5 UHS fan speed and bypass controllers are shown together with power excess checker block and fan/bypass switching block (RS flip flop). Because in the current model the fan power is not reflected in the shaft braking torque directly, it is necessary to check whether there is still a positive power excess after the clutch is locked. If not, power excess checker will stop the UHS fans. If the compressor inlet temperature falls below some prescribed value, then the switching block stops the fans and activates the bypass control.

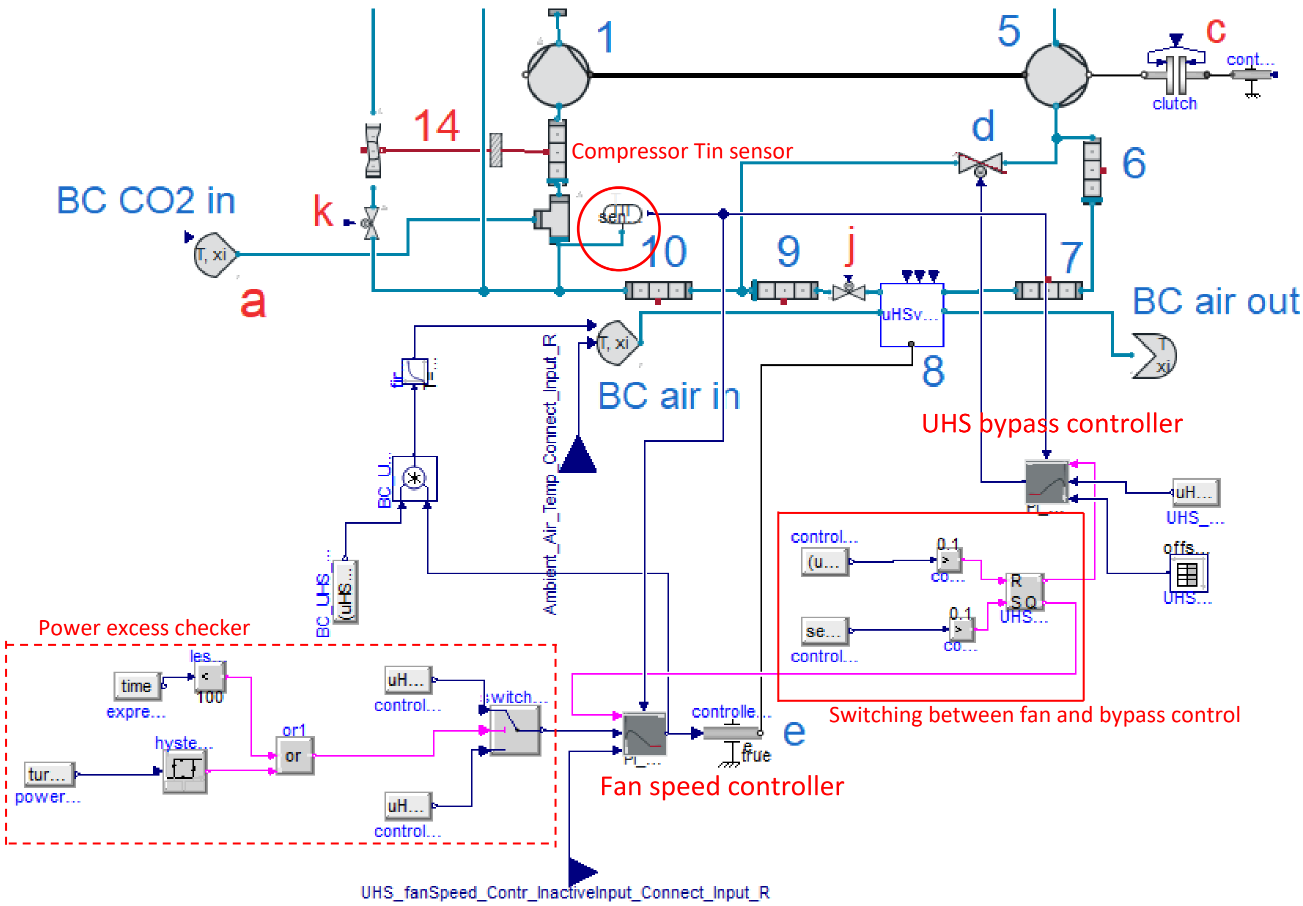

Figure 5: UHS fan speed and bypass control layout

5.4 Compressor suction pressure control

The development of decay heat with changing ambient air temperature cause changes in the CO_2 density in the loop. These changes in the density cause changes in the pressure and therefore deviations from the loop design conditions. To accommodate to these changing conditions within the loop, different approaches may be adopted. In the current model, changing loop filling (a) and CO_2 blow off to the atmosphere (m) are used. These two control logics are shown in Figure 6. Here, the blow off valve operates on/off and the loop filling is controlled by a PI controller with its coefficients accessible from the FMU model outside environment. The "not1" component switches between "k" and "m" controllers (see Figure 3).

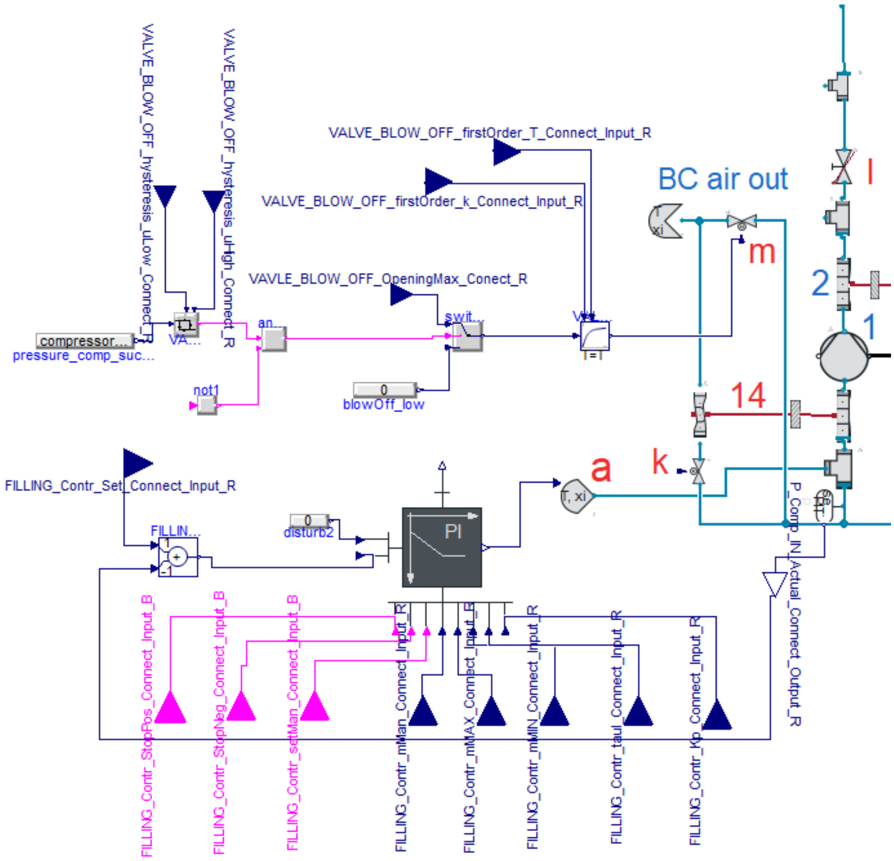

Figure 6: Compressor suction pressure control

5.5 CHX water outlet temperature control

There is a requirement from the CHX designer to keep water temperature at CHX outlet equal to 150 °C. To fulfil this requirement, control valve "n" is placed at the CHX water outlet as shown in Figure 7. There are two controller variables that are accessible from the FMU outside, namely the water outlet setting temperature and the valve opening if controller is off (that is, in manual mode) from 0 to 100 seconds).

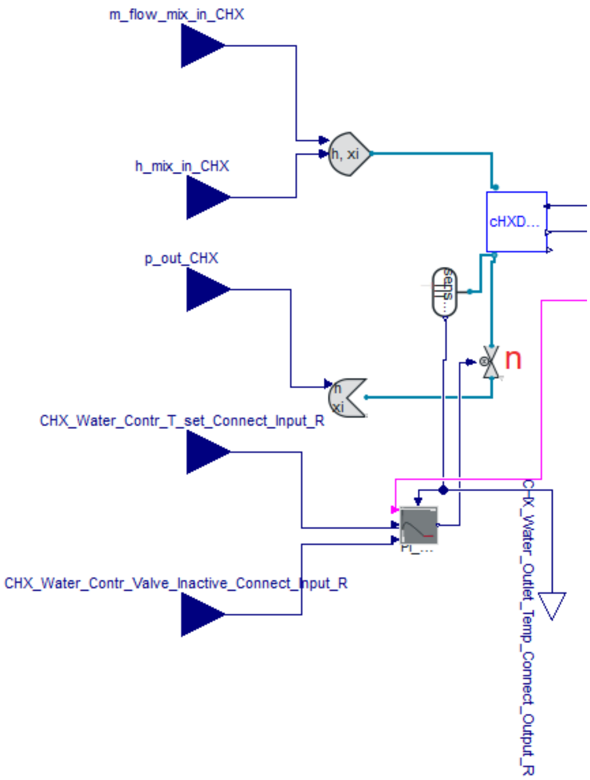

Figure 7: CHX water outlet temperature control

6 sCO_2 loop FMU model inputs/outputs

In this chapter, FMU I/O variables and constants are listed and described. In the current FMU model, the sCO_2 loop system initial conditions are defined in accordance with Table 3. From the point of view of the below listed inputs, the initial state of the FMU model is defined inside the FMU and is thus fixed unless the FMU is started from previously calculated and recorded conditions.

Table 3: FMU sCO_2 loop model initial state

Component Parameters	Unit	Value
UHS CO_2 side		
p	bara	2
T	°C	45
UHS air side		
p	bara	1
T	°C	45
Piping		
p	bara	2
T	°C	20
Turbomachinery		
rotational speed	rpm	100

The inputs mainly correspond with the sCO_2 loop control logic except for the CHX water side, where coupling between Dymola sCO_2 loop model in a form of FMU and Konvoi simulator takes place, and except the ambient air temperature, which is also a thermodynamic property.

6.1 sCO_2 loop FMU model inputs

Input variables/constants			
Variable name in the model	**Unit**	**Starting value**	**Comment**
Ambient air temperature			
Ambient_Air_Temp_Connect_Input_R	K	45+273.15	Ambient air temperature
CHX (3,n)			
m_flow_mix_in_CHX	kg/s	0.1	Water mass flow at CHX inlet. Flow of information is from Konvoi simulator to Dymola FMU
h_mix_in_CHX	J/kg	90.488e3	Water enthalpy at CHX inlet. Flow of information is from Konvoi simulator to Dymola FMU
p_out_CHX	Pa (abs)	7010139	Water pressure at CHX outlet. Flow of information is from Konvoi simulator to Dymola FMU
CHX_Water_Contr_T_set_Connect_Input_R	°C	150	Water temperature at CHX outlet control
CHX_Water_Contr_Valve_Inactive_Connect_Input_R	1	1	Valve opening if controller is in manual mode (0-100 sec)
Starting reduction valve (h)			
VALVE_START_REDUC_Opening_Connect_Input_R	1	0	Valve opening (Table 4)
Starting control valve (i)			
VALVE_START_CONTR_Opening_Connect_Input_R	1	0	Valve opening (Table 5)
Starting CO2 pressure in front of the starting valves			
Starting_CO2_Press_Connect_Input_R	Pa (abs)	90e5	CO_2 pressure source (Table 6)
Starting_CO2_Temp_Connect_Input_R	K	80+273.15	CO_2 temperature source (all time)
Pressure control valve (k in Figure 3) controller (active during starting procedure) (PI)			
VALVE_PRESSURE_CONTR_Opening_Inactive_Connect_Input_R	1	0	Valve opening if controller is in manual mode (zero for all time)
VALVE_PRESSURE_CONTR_Press_Set_Connect_Input_R	bar abs	126	CO_2 pressure at compresssor inlet set point
VALVE_PRESSURE_CONTR_set_Auto_Connect_Input_B	true/false	true	If true, controller is in automatic mode. From 0 to 900 sec = true then false

Input variables/constants			
Variable name in the model	**Unit**	**Starting value**	**Comment**
TAC speed during start-up (in Figure 4 the dashed line block)			
TAC_Speed_Clutch_Set_Pressure_Connect_Input_R	bara	130	This is a pressure (at compressor suction) above which the auxiliary clutch lock. This pressure is set higher than compressor inlet set pressure
TAC_Speed_Contr_Delay_Connect_Input_R	second	300	This is a time delay between clutch lock and long term TAC speed control switching on (to let the system settle)
TAC speed long term control (in Figure 4 the full line block)			
TAC_Speed_Contr_T_turb_IN_Set_Connect_Input_R	°C	250	Turbine inlet temperature set point
TAC_Speed_Contr_Inactive_Connect_Input_R	rad/s	1885	This is a speed (18 000 rpm) of the clutch part that is connected to the TAC controller. This speed is a speed of TAC after clutch is locked. Unfortunately now the autonomous TAC speed evolution before the clutch is locked is not surveyed by the TAC controler. This speed is kept constant during the delay time
UHS fan speed (e,8) and bypass (d) control (Figure 5)			
UHS_FanSpeed_Contr_T_out_max_Connect_Input_R	K	60+273.15	UHS CO_2 outlet maximum temperature. If UHS bypass is on then reaching this value will cause switching it off
UHS_FanSpeed_Contr_T_out_nom_Connect_Input_R	K	55+273.15	UHS CO2 nominal outlet temperature
UHS_FanSpeed_Contr_T_out_min_Connect_Input_R	K	50+273.15	UHS CO2 minimum outlet temperature. If UHS bypass is off then reaching this value will cause switching it on
UHS_fanSpeed_Contr_InactiveInput_Connect_Input_R	rad/s	1*2*3.1415926/60	Fan speed if controller is in manual mode (manual mode = 0 – 100 sec; defined internally in the model)
Note to bypass control: no I/O connector is available from the FMU outside in the current model. During the start-up procedure the bypass valve is 10% open. Later is closes to 1% opening to let some small CO_2 amount flow through it (numerical reasons)			

Input variables/constants			
Variable name in the model	**Unit**	**Starting value**	**Comment**
Filling control (a) (Figure 6)			
FILLING_Contr_Kp_Connect_Input_R	kg/s/bar	20	Proportional constant of the controller
FILLING_Contr_tauI_Connect_Input_R	bar*s/kg/s	0.1	Integral constant of the controller
FILLING_Contr_mMIN_Connect_Input_R	kg/s	0	Minimum mass flow rate (always zero)
FILLING_Contr_mMAX_Connect_Input_R	kg/s	5	Maximum mass flow rate
FILLING_Contr_mMan_Connect_Input_R	kg/s	0	Mass flow if controller is in manual mode
FILLING_Contr_Set_Connect_Input_R	bar abs	124	Compressor inlet pressure set value
FILLING_Contr_setMan_Connect_Input_B	true/false	true	If true, controller is in manual mode. From 0 to 500 sec controller is in manual mode
FILLING_Contr_StopNeg_Connect_Input_B	true/false	false	If true, control signal wil not decrease. Always false
FILLING_Contr_StopPos_Connect_Input_B	true/false	false	If true, control signal wil not increase. Always false
Blow off valve (m) control (Figure 6)			
VALVE_BLOW_OFF_hysteresis_uLow_Connect_R	Pa abs	125e5	Compressor inlet pressure low pressure margin
VALVE_BLOW_OFF_hysteresis_uHigh_Connect_R	Pa abs	126e5	Compressor inlet pressure high pressure margin
VALVE_BLOW_OFF_firstOrder_k_Connect_Input_R	1	1	Gain for the transfer function
VALVE_BLOW_OFF_firstOrder_T_Connect_Input_R	second	25	Time constant for the transfer function

6.2 sCO_2 loop FMU model outputs

Output variables			
Variable name in the model	**Unit**	**Starting value**	**Comment**
CHX (3,n)			
CHX_CO2_MassFlow_Out_Connect_Output_R	kg/s		
CHX_CO2_Temp_Out_Connect_Output_R	K		
CHX_CO2_Press_Out_Connect_Output_R	Pa abs		
CHX_CO2_MassFlow_In_Connect_Output_R	kg/s		
CHX_CO2_Temp_In_Connect_Output_R	K		
CHX_CO2_Press_In_Connect_Output_R	Pa abs		
p_in_CHX	Pa abs		Water steam pressure at CHX inlet
m_flow_mix_out_CHX	kg/s		Water mass flow rate at CHX outlet
h_mix_out_CHX	J/kg		Water enthalpy at CHX outlet
CHX_water_dp_Connect_Output_R	Pa		Water pressure difference between inlet to the CHX and outlet of the water condensate temperature control
CHX_Water_Outlet_Temp_Connect_Output_R	°C		
Starting reduction valve (h)			
Valve_Start_Reduc_MassFlow_Out_Connect_Output_R	kg/s		Starting CO2 injection
Valve_Start_Reduc_Temp_Out_Connect_Output_R	K		Temperature behind starting reduction valve
Valve_Start_Reduc_Press_Out_Connect_Output_R	Pa abs		Pressure behind starting reduction valve
Pressure control valve (k)			
VALVE_PRESSURE_CONTR_Temp_Out_Connect_Output_R	K		Temperature behind pressure control valve (blow off to the atmosphere through the starting cooler)
VALVE_PRESSURE_CONTR_Pressure_Out_Connect_Output_R	Pa abs		Pressure behind pressure control valve (blow off to the atmosphere through the starting cooler)
VALVE_PRESSURE_CONTR_MassFlow_In_Connect_Output_R	kg/s		
VALVE_PRESSURE_CONTR_Temp_In_Connect_Output_R	K		
VALVE_PRESSURE_CONTR_Pressure_In_Connect_Output_R	Pa abs		
VALVE_PRESSURE_CONTR_opening_Connect_Out_R	1		

Output variables			
Variable name in the model	**Unit**	**Starting value**	**Comment**
Turbine (5)			
TURBINE_Temp_Out_Connect_Output_R	K		
TURBINE_Press_Out_Connect_Output_R	Pa abs		
TURBINE_MassFlow_In_Connect_Output_R	kg/s		
TURBINE_Temp_In_Connect_Output_R	K		
TURBINE_Press_In_Connect_Output_R	Pa abs		
TURBINE_Power_Actual_Connect_Output_R	W		
Compressor (1)			
COMPRESSOR_Inlet_MassFlow_Connect_Output_R	kg/s		
COMPRESSOR_Inlet_Temperature_Connect_Output_R	K		
COMPRESSOR_Inlet_Pressure_Connect_Output_R	Pa abs		
COMPRESSOR_Outlet_Temperature_Connect_Output_R	K		
COMPRESSOR_Outlet_Pressure_Connect_Output_R	Pa abs		
COMPRESSOR_Power_Actual_Connect_Output_R	W		
UHS (8)			
UHS_CO2_MassFlow_Out_Connect_Output_R	kg/s		
UHS_CO2_Temp_Out_Connect_Output_R	K		
UHS_CO2_Press_Out_Connect_Output_R	Pa abs		
UHS_CO2_MassFlow_In_Connect_Output_R	kg/s		
UHS_CO2_Temp_In_Connect_Output_R	K		
UHS_CO2_Press_In_Connect_Output_R	Pa abs		
UHS_FAN_Power_Connect_Output_R	W		
UHS_Air_Mass_Flow_Connect_Output_R	kg/s		
UHS_FAN_Speed_Connect_Output_R	rpm		

Output variables			
Variable name in the model	**Unit**	**Starting value**	**Comment**
Filling (a)			
FILLING_Mass_Flow_Connect_Output_R	kg/s		Compressor suction pressure controller CO2 injection
Blow off valve (m)			
VALVE_BLOW_OFF_Opening_Connect_Output_R	1		Compressor suction pressure control (long term operation)
Valve_BlowOff_MassFlow_Connect_Output_R	kg/s		
UHS bypass (d)			
VALVE_UHS_BYPASS_opening	1		
Check valve (l)			
Valve_Check_Comp_Out_MassFlow_Connect_Output_R	kg/s		Compressor oulet check valve
Power balance			
Power_Balance_Total_Connect_Output_R	W		Total power balance equals turbine power output – compressor power input – UHS fans power input

6.3 sCO_2 loop FMU model input tables

Table 4: Valve “h” opening

VALVE_START_REDUC_Opening_Connect_Input_R	
time	opening
[s]	[1]
0	0
200	1
400	1
410	0
700	0

Table 5: Valve “i” opening

VALVE_START_CONTR_Opening_Connect_Input_R	
time	opening
[s]	[1]
0	0
300	0
310	0.2
400	0.2
430	0
700	0

Table 6: Starting CO_2 pressure

Starting_CO2_Press_Connect_Input_R	
time	pressure
[s]	[Pa abs]
0	90e5
60	90e5
180	210e5
700	210e5

These tables define the course of the valves opening and CO_2 pressure in the starting tank. Where there is a change in the parameter value this change evolves linearly during the specified time span.

These FMU model inputs, when applied to the input connectors, ensure the start-up of the loop. Further elaboration with respect to the start-up is nevertheless needed to make the start-up fully automatic for different ambient air temperature conditions as well as for the different conditions of the water steam at the CHX inlet.

6.4 sCO_2 loop FMU and Konvoi simulator CHX interface

In Figure 8, FMU model input (full triangle) and output (blank triangle) connectors are shown in detail together with CHX water inlet and outlet height from the ground. At the CHX water outlet, the pressure interface is located downstream from the control valve.

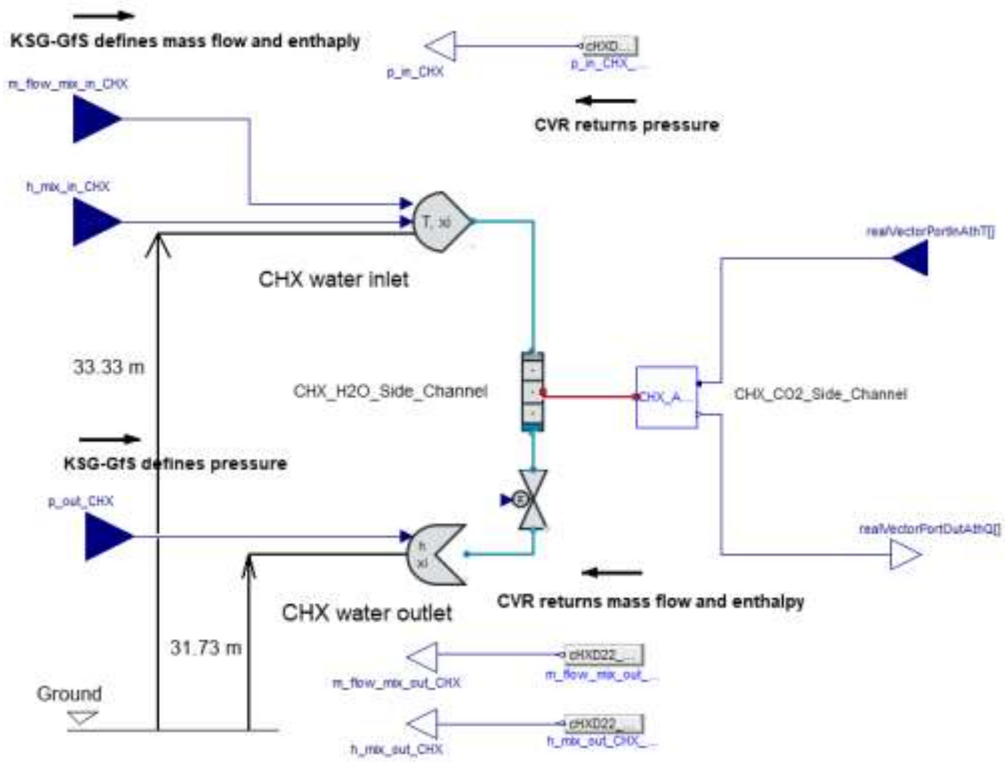

Figure 8: Detail of Konvoi – Dymola CHX interface

7 sCO_2 loop FMU model solver basic information

The sCO_2 loop FMU model was exported from the Dymola development environment in a form suitable for Co-simulation with a Cvode solver. The accuracy variable fmi_rTol that approximately defines the number of expected true digits in the solution is expected to be about 1e-5. The recommended fmi_rTol parameter setting is between the values 1e-5 and 1e-8. Tests in Dymola for the current model revealed that setting fmi_rTol to be 1e-5 is a good choice as more strict values do not lead to different results but have an adverse impact on the computational time. When performing calculations of the coupled system Athlet-Dymola, the following settings were applied:

- Communication time step between Athlet and Dymola was set to 0.5 s

Dymola solver settings:

- Cvode solver
- Start time 0 s
- Stop time 363 000 s
- Number of intervals 10 000
- Equidistant time grid

8 Conclusion

In this deliverable, the sCO_2 loop Dymola model in a form of FMU was prepared and made available to KSG for coupled simulation with the Konvoi simulator. This report describes the basics of the model architecture, its control logic and input/output variables.

As the Dymola sCO_2 loop model is still under development, the FMU will also be changed in the future. From this point of view, the future work will focus on implementing:

- actual CHX and UHS design with respect to their relevant layout within the reactor building
- impactless transition from the push-up start to long term TAC speed control

In the future, it will also be necessary to address the issue of the sCO_2 loop start-up during the low ambient air temperatures period when two-phase CO_2 may occur within the loop.