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## APPLICATION EXAMPLE

# Equipment Modules for PCS 7 using the example of the Chemical Industry

SIMATIC PCS 7 V9.1

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# 1. Introduction

## 1.1. Overview

The standardization of automation engineering for processing plants, such as in the chemical industry, is a major challenge. Different process steps and procedures, different equipment and flexibility in the production make the task even more difficult.

One approach for standardization is structuring the plant according to the physical model of ISA 106. This specifies the lower four levels, i.e. plant, unit, plant unit and control module. A plant always consists of units. The plant sections can, in turn, contain standardized plant sections that are based on equipment modules. An equipment module comprises both the physical equipment and the user program.

This application example contains standardized equipment modules in the form of software typicals that are provided in SIMATIC PCS 7 as a multiproject.

Using them offers the following benefits:

- A reduction in the expertise necessary to develop applications
- Less effort needed for configuration
- Re-use of field-proven control strategies
- Harmonized structures
- Flexible structuring and adjustment of partial automation solutions

The equipment modules offer a template that comprises the typical components of a partial automation solution, incl. open- and closed-loop control, the necessary logic and visualization.

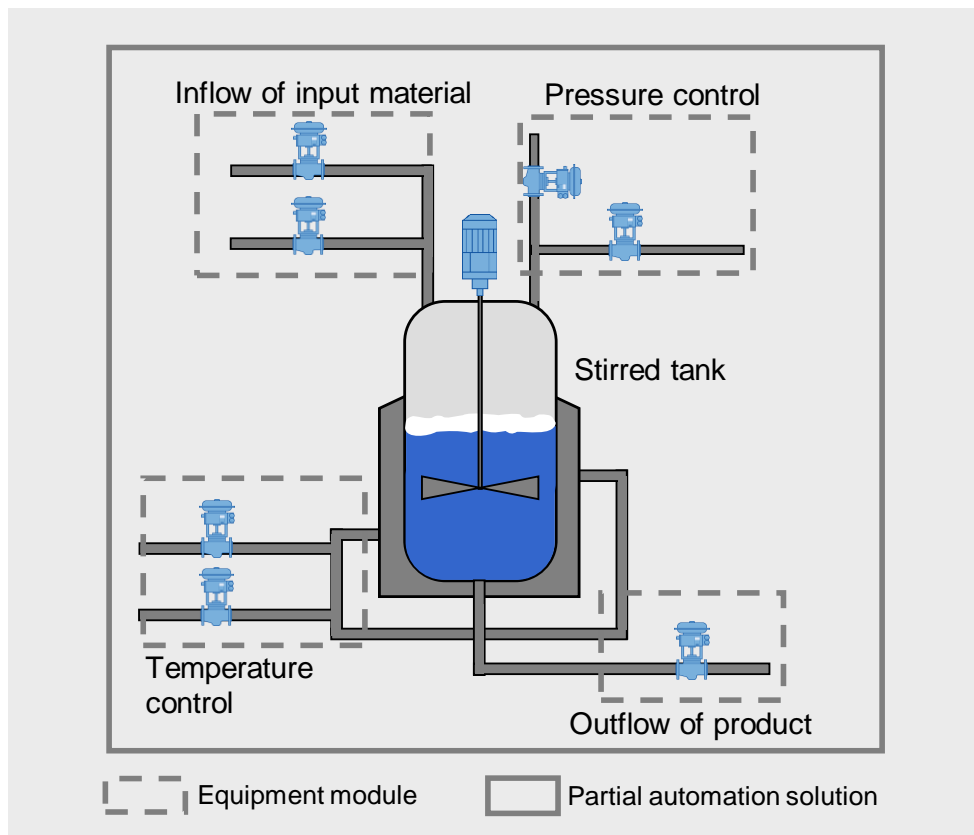
An equipment module is configured independently of the automation hardware and is a component of a pre-configured PCS 7 project including the process visualization system. Due to hardware-independent configuration and the modular structure, it is possible to integrate and use the equipment modules in PCS 7 projects in any way you like.

Equipment modules are composed of control modules (CMs). Function blocks of the PCS 7 Advanced Process Library (APL) are used to create a control module.

## 1.2. Mode of operation

The equipment module concept provides pre-engineered and unified components for creating an automation solution, e.g. metering or temperature control.

The diagram below shows the equipment modules as components of a partial automation solution as an example.



The equipment module concept provides pre-engineered and unified components for creating an automation solution, e.g. metering or temperature control.

The equipment modules are implemented in the PCS 7 multiproject as follows:

- One project for the automation system (AS) and one project for the operator station (OS) are contained in the component view.
- A hierarchy folder has been created in the plant hierarchy for each equipment module.
- The master data library contains all of the control module types in use.

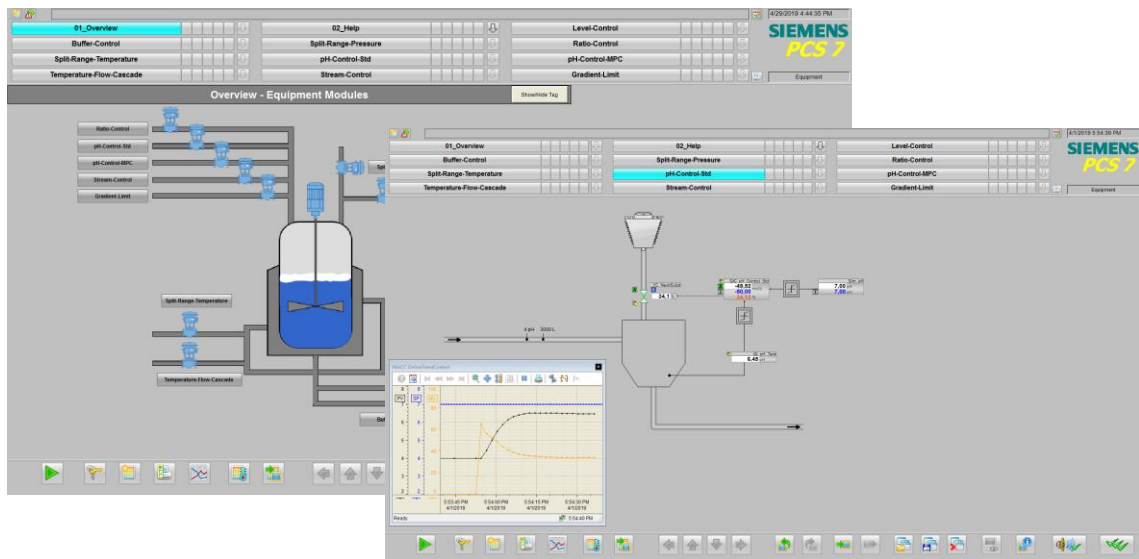
In the AS project, all the open- and closed-loop control functions are implemented in the form of Continuous Function Charts (CFCs). Apart from this, the AS project contains a simulation that approximately simulates a procedure, e.g. a filling level change within an equipment module.

The OS project contains visualization by means of one process picture per equipment module and shows:

- Schematic representation of the equipment module
- Approximately simulated process response
- Relevant parameters (KPI: Key Performance Indicator)
- Monitoring of control performance

The overview picture and the structure of a process picture of an equipment module are described below. For a detailed description of the core functionality of an equipment module, please refer to Chapter 5 "[Equipment Modules](#)".

## Visualization interface



The visualization interface of the equipment modules consists of an overview picture and a process picture for each equipment module.

### Overview picture

The overview picture contains a schematic representation in the form of a material flow diagram of the process engineering system that includes all the equipment modules in the example project.

Using the pushbutton of an equipment module, you switch to the respective process picture that contains the functionality and the specific information of an equipment module. The system represents the process pictures in the form of an appropriate section of the P&ID of a system.

### Process picture

The process picture of an equipment module consists of the following parts:

- Schematic representation (P&ID)
- Simulation
- Faceplates for controlling the individual components (units)
- Trend curve representation to visualize control response

In the process picture, operators are provided with an overview of the respective equipment module and can understand the runtime response on a time basis.

### Delimitation

The process behavior is not simulated in detail within the equipment module.

### Required knowledge

Basic knowledge of the following specialist fields is a prerequisite:

- Configuring using SIMATIC PCS 7 CM technology and the APL
- Knowledge of control technology
- Basic knowledge of process technology

## 1.3. Components used

This application example has been created with the following hardware and software components:

Component	Note
SIMATIC PCS 7 ES/OS IPC647E W10	For the PCS 7 V9.1 example project
SIMATIC PCS 7 V9.1	Part of SIMATIC PCS 7 ES/OS IPC647E W10
Advanced Process Library V9.1	Part of SIMATIC PCS 7 V9.1
S7-PLCSIM	Not part of SIMATIC PCS 7 V9.1; appropriate licenses are required.

### NOTE

In case of different hardware, please take heed of the minimum requirements for installing the software components. The minimum requirements can be found in the Readme of the PCS 7 under follow link:  
<https://support.industry.siemens.com/cs/ww/de/view/109780270>.

This application example consists of the following components:

Component	Note
53843373_EquipmentModules_PROJ_PCS7V91.zip	Example project
53843373_EquipmentModules_DOC_PCS7V91_en.pdf	This document

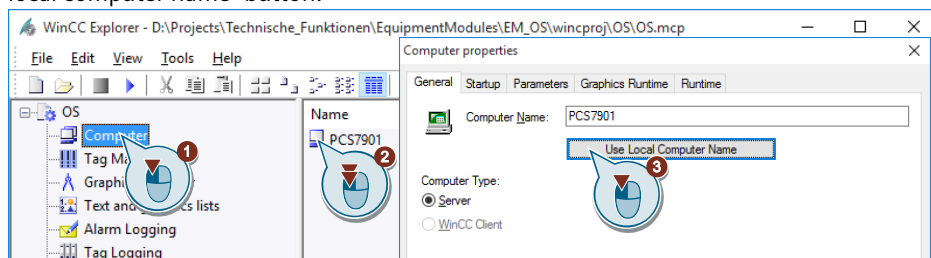


# 2. Preparation and commissioning

## 2.1. Preparation

The following instructions describe commissioning of the equipment modules by simulating the controller using the "S7-PLCSIM" program. If you are using a real controller, you must configure existing hardware components in the hardware settings.

1. Copy file "53843373\_EquipmentModules\_PROJ\_PCS7V91.zip" to any folder on the configuration PC and then open SIMATIC Manager.
2. Click on "File > Retrieve" on the menu bar and select file "53843373\_EquipmentModules\_PROJ\_PCS7V91.zip". Then click on "Open" to confirm.
3. Choose the folder where you want to save the project and click on "OK" to confirm.  
The project is retrieved.
4. Confirm the "Retrieve" dialog by clicking on the "OK" button and then click on "Yes" in the dialog to open the project.
5. Right-click on "EquipmentModules\_OS > OS01 > WinCC Appl. > OS" and then click on the "Open object" menu command.
6. Confirm the "Configured server not available" dialog with "OK".
7. In the WinCC Explorer, open the properties of your computer and, in the opened Properties dialog, click on the "Use local computer name" button.



8. Confirm the "Change computer name" message with "OK".
9. In the WinCC Explorer, click on "File > Exit" and in the subsequent dialog select "Terminate WinCC Explorer and close project".
10. Then confirm with "OK".
11. Reopen the WinCC Explorer as described in step 5.
12. Open by double-clicking on "Variables library".
13. In the "WinCC Configuration Studio", open "Variables library > SIMATIC S7 Protocol Suite > TCP/IP" and select the menu command "System parameters".
14. In the "Unit" tab, check the "Logical device names" setting. If the "S7 PLCSIM" program is used, the device name "PLCSIM.TCPIP.12" is selected.  
A restart is required after a device name change.

### NOTE

If the OS cannot establish a connection with the AS (grayed out module icons), select the logical device name "CP\_H1\_1" and restart the OS runtime.

## 2.2. Commissioning

You can commission the equipment modules after starting the simulation.  
You can find a detailed description in Chapter 5.

### Starting the simulation (S7 PLCSIM)

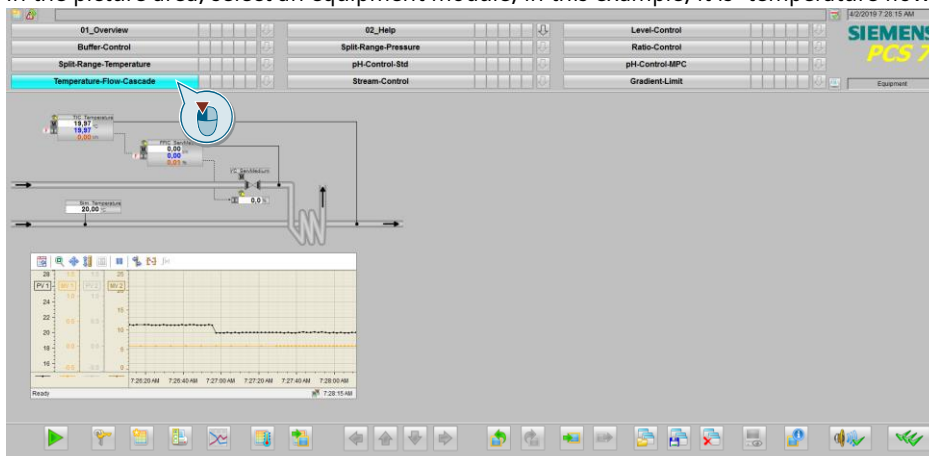
To start the simulation, proceed according to the following instructions:

1. Select "Extras > Simulate Modules" from the menu.  
The "S7 PLCSIM" dialog window opens.
2. In the "Open project" dialog, select "Open project from file".
3. Select file "EquipmentModules.plc" from path <project path>\Function\EM\EquipmentModules.plc<.
4. In the menu, change "PLCSIM(MPI)" to "PLCSIM(TCP/IP)".
5. In the menu, select "Execute > key switch position > RUN-P".

### Activate OS (WinCC runtime)

To activate the OS, proceed according to the following instructions:

1. Right-click on the OS and select the menu "Open object".
2. To activate the OS (WinCC Runtime), select the menu command "File > Activate" in WinCC Explorer.
3. In the "System Login" dialog, enter user name "Equipment" as the "Login" and "Modules" as the password and then click on "OK" to confirm.
4. In the picture area, select an equipment module; in this example, it is "temperature flow cascade".



# 3. Integrating the Equipment Module in the user project

## 3.1. Preparation

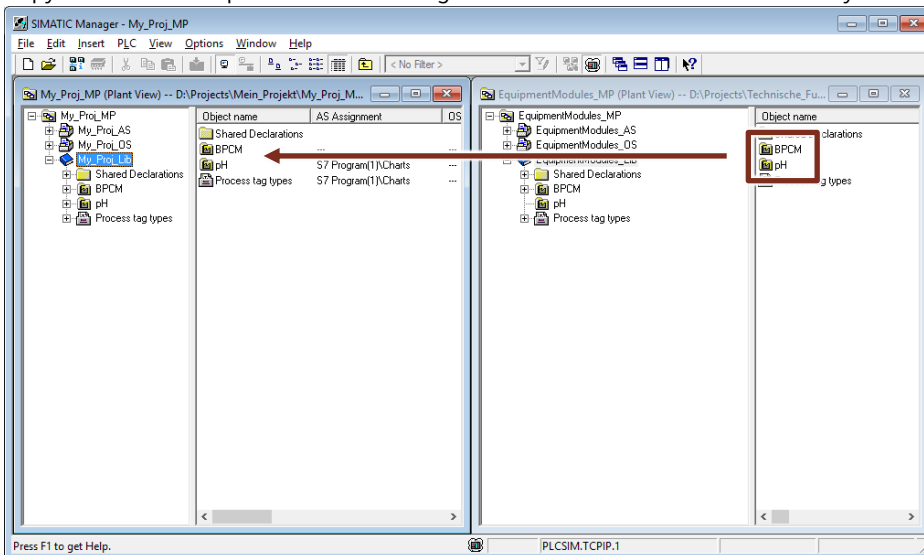
1. Copy the file "53843373\_EquipmentModules\_PROJ\_PCS7V91.zip" to the configuration PC and then open the SIMATIC Manager.
2. Click on "File > Retrieve" in the menu bar and select the file "53843373\_EquipmentModules\_PROJ\_PCS7V91.zip". Then confirm by clicking on "Open".
3. Select the folder in which the project will be saved and confirm with the "OK" button. The project will be extracted.
4. In the "Retrieve" dialog, click on the "OK" button and then click on "Yes" in the dialog to open the project.
5. Switch to the "Plant view".
6. At the same time, open the project in which the Equipment Modules is to be integrated.

## 3.2. Copying templates

### NOTE

If you have already worked with CMTs in your existing project, then check that they are identical before skipping to the following steps, since this can lead to errors in your existing project or in the Unit Template you want to integrate.

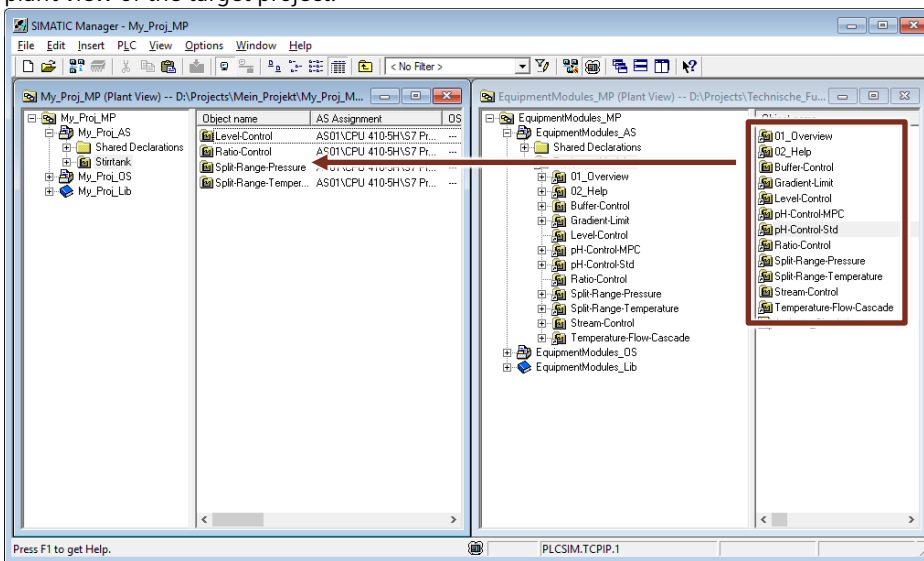
1. Switch to the plant view.
2. Copy the "BCM" and "pH" folder containing the CMTs from the master data library into the target project.



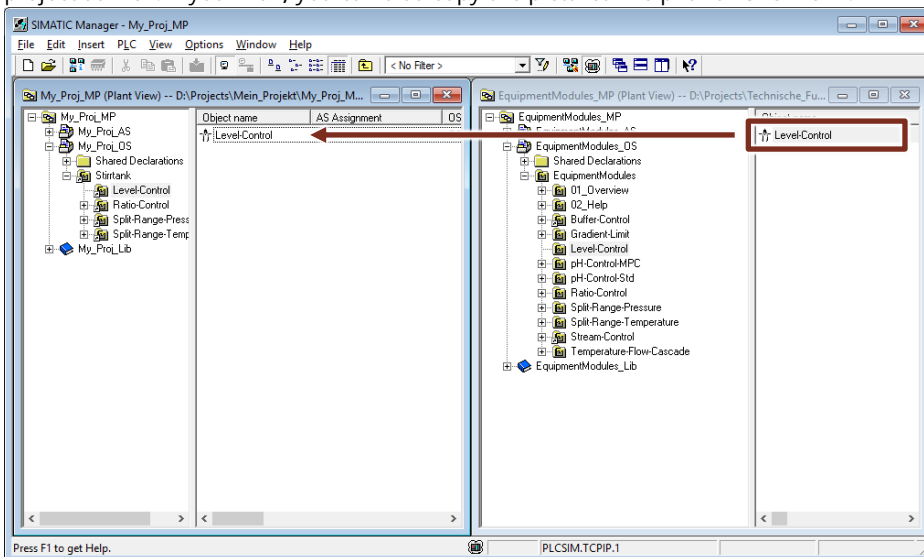
3. Copy the Enumerations from the master data library into the target project.

### 3.3. Copying Equipment Module

1. Copy the hierarchy folder with the desired Equipment Module from the AS project of the Equipment Module to the plant view of the target project.



2. Copy the corresponding process screens from the OS project of the Equipment Module to the plant view of the target project as well. If you wish, you can also copy the pictures "Help" and "Overview".



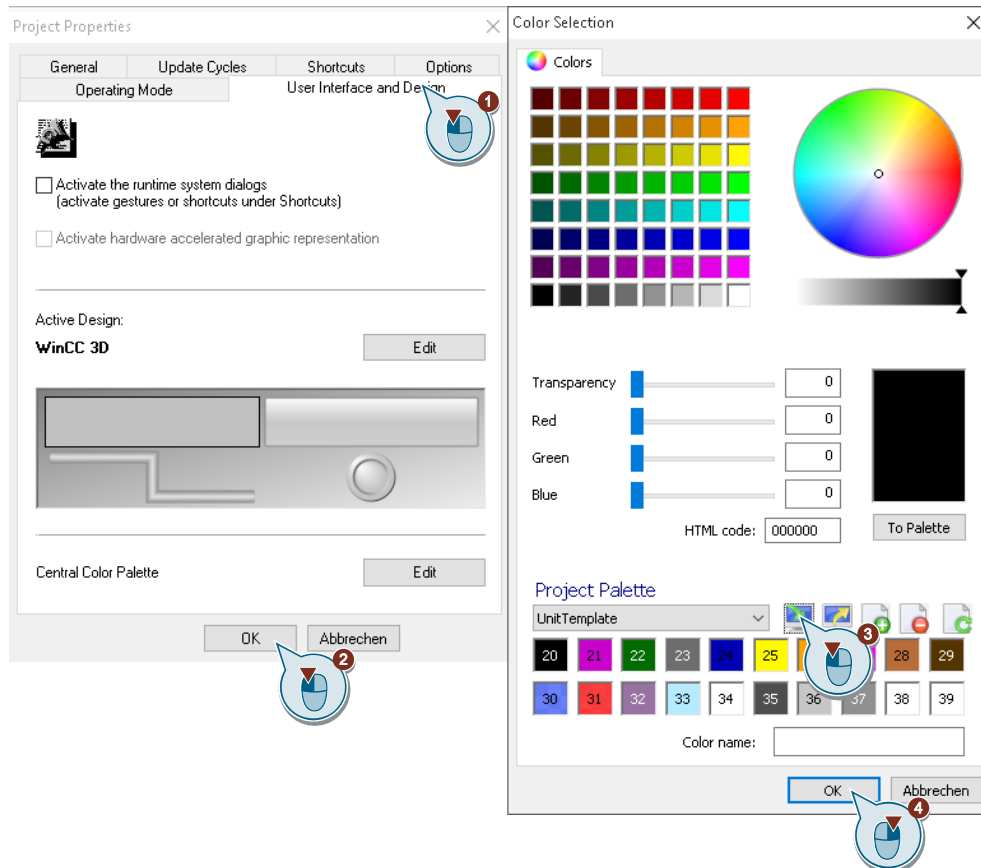
#### NOTE

When copying the process screens, make sure that you copy the pictures to the hierarchy level of the target project, which is configured as an OS area.

## 3.4. Adapting the OS project

In order to facilitate the changing of colors in the process screen from a central point, a central color palette was created in the OS project. To display these colors in the process screen of your own project, you must import the relevant color palette.

1. Select the "OS" in WinCC Explorer and choose "Object properties..." in the shortcut menu.
2. Choose the "User Interface and Design" tab and click the "Edit" button.
3. Import the palette into your own project by means of the "Overwrite" option. The color palette is located in the project folder of the Unit Template at the path: "<Project path>\EquipmentModules\EM\_OS\wincproj\OS\GraCS\UnitTemplate.xml". All existing colors will be replaced.



**NOTE** Please note that all colors are always used when exporting/importing color palettes. It is not possible to export partial color tables.

If you have created your own color tables in your project, you can also export them and use an editor to merge the tables in the XML file. Otherwise, you can create a new color table in your project and configure the colors individually. Make sure, too, that the color index does not change, otherwise you will have to adjust the color settings of the objects in the process screen. Of course, it is up to you to change the colors according to your requirements.

# 4. Control Module

## 4.1. Introduction

A control module is used to control individual pieces of equipment, like motors, valves, and controllers, for example. The necessary blocks for carrying out this job, e.g. controlling a valve, are combined in a control module (CM). If a control module is used several times in the project, e.g. with different characteristics, you create a control module type (CMT) from it in PCS 7 and store it in the master data library. You can use this CMT in a flexible way anywhere in the project as an instance with different characteristics (variants).

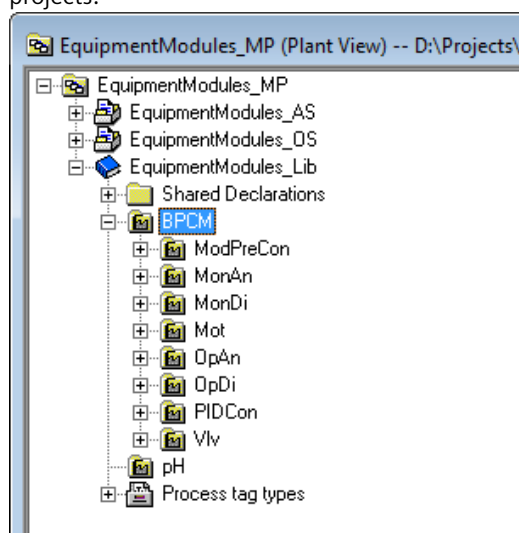
Using the technology allows to test automation projects using the program logic even if you do not have the real hardware.

### NOTE

The application example "Control Module (CM) Technology - Efficient Engineering with SIMATIC PCS 7" gives you a general overview of how to create, extend, and instantiate a CMT. The application example is available at the following link: <https://support.industry.siemens.com/cs/ww/en/view/109475748>

### Master data library

This chapter gives you detailed information about the structure and mode of operation of the CMTs on which the equipment modules are based. All of the CMTs are stored in the "EquipmentModules\_Lib" master data library of the PCS 7 projects.



The CMTs are sub-divided as follows:

- Multivariable controller in the "ModPreCon" folder
- Analog measured value display in the "MonAn" folder
- Digital measured value display in the "MonDi" folder
- Motor in the "Mot" folder
- Analog value input in the "OpAn" folder
- Digital value input in the "OpDi" folder
- Controller in the "PIDCon" folder
- Valve in the "Vlv" folder

CMTs are of compact structure, i.e. all the relevant blocks are at defined locations. For example, channel blocks are always in chart partition B of a CFC.

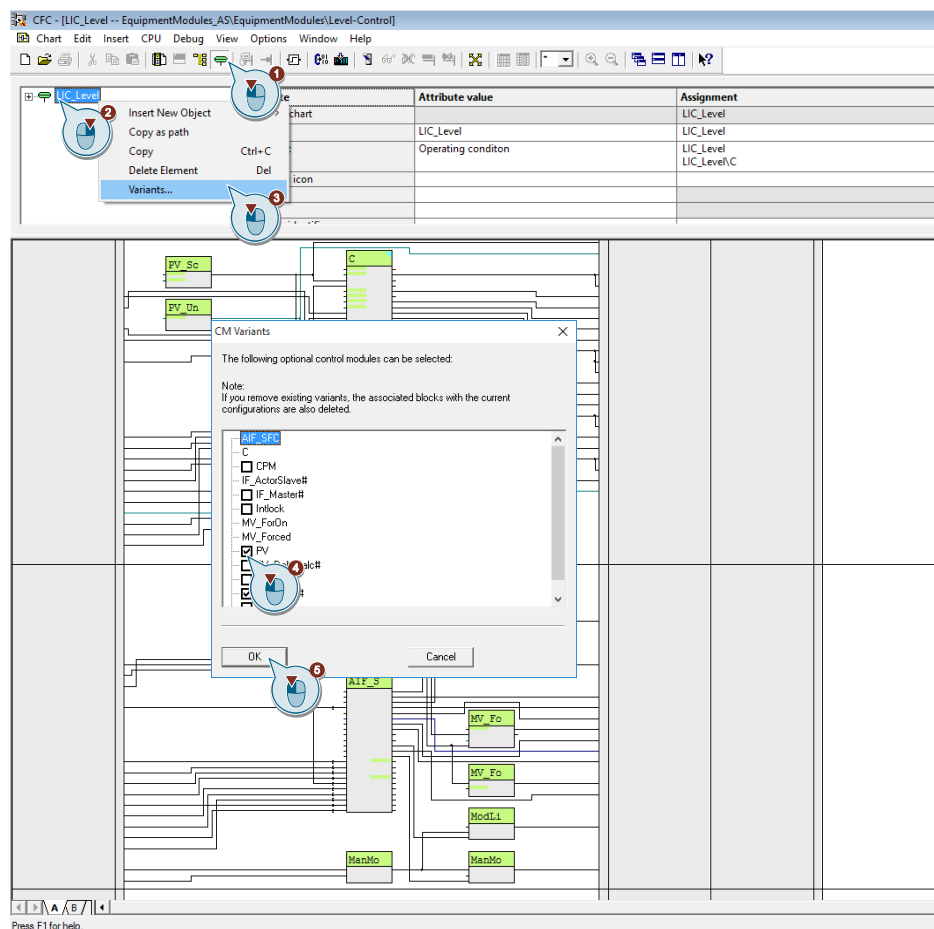
### NOTE

Folder "pH" contains the source files of the pH simulation and the conversion block from pH value to concentration difference. The functions and structure of the block are described in Section [6.5](#).

## Selecting a variant

A variant and the options that are necessary for solving an automation task are determined in the instance.

1. To do this, the system displays the technological I/Os in the CFC,
2. the available variants are displayed via the shortcut menu and
3. the functionality that is necessary for the automation task is determined by selecting the options.



## 4.2. Basic Control Module Type Library

The Basic Control Modules (BCM) in the form of a Type Library are available for SIMATIC PCS 7 as a master data library and contain typical, pre-projected and tested CMT. The BCM are created with CM technology and enable more efficient engineering through standardized program components.

The following benefits are achieved by using the BCM Type Library:

- Extensive library for different applications and industries
- Reduction of the project planning effort
- Reduced maintenance
- Standardized structures

The BCM Type Library offers typical components as a template for building automation solutions. The CMT of the BCM Type Library contain all necessary function and channel blocks and can be adapted to the project-specific conditions by instantiation.

The BCM's are based on the SIMATIC PCS 7 Advanced Process Library (APL) and Industry Library (IL), are hardware-independent, pre-configured and modular.

The library provides the following CMT groups:

- MonAn: Analog measured value display
- MonDi: Digital measured value display (binary signal)
- OpAn: Setting an analog value by the operator
- OpDi: Setting a binary value by the operator
- PIDConL Controller for standard and cascade control loops
- Mot: Motor control with simple speed control
- MotSpdC: Motor control with variable speed control
- Vlv: Valve actuation with two defined positions
- VlvAn: Valve control with analog control valve

**NOTE**

The BCM library uses the name of the central technology block of the APL.

**NOTE**

A detailed description of each CMT with function description, supported variants and control elements you can find in the application example "Control Module (CM) Technology - Efficient Engineering with SIMATIC PCS 7" under the link:

<https://support.industry.siemens.com/cs/ww/en/view/109475748>



## 4.3. "ModPreCon" 4x4 multivariable controller

The multivariable controller CMTs contains controller blocks, a control performance monitoring system, interface blocks (slave/actuator) and the link to sequential function charts.

The CMTs are pre-configured for different areas of application. Using options, you select or deselect blocks, e.g. the channel blocks, that are needed for the application.

The following CMTs are available:

- "ModPreCon" for multivariable control using up to four controlled variables
- "ModPreCon4Valve" for one controlled variable with several disturbance variables

### 4.3.1. Standard multivariable controller

CMT "ModPreCon" is used for multivariable controllers. Unlike the "PIDCon", multivariable controllers master up to four manipulated and controlled variables that are interacting with each other.

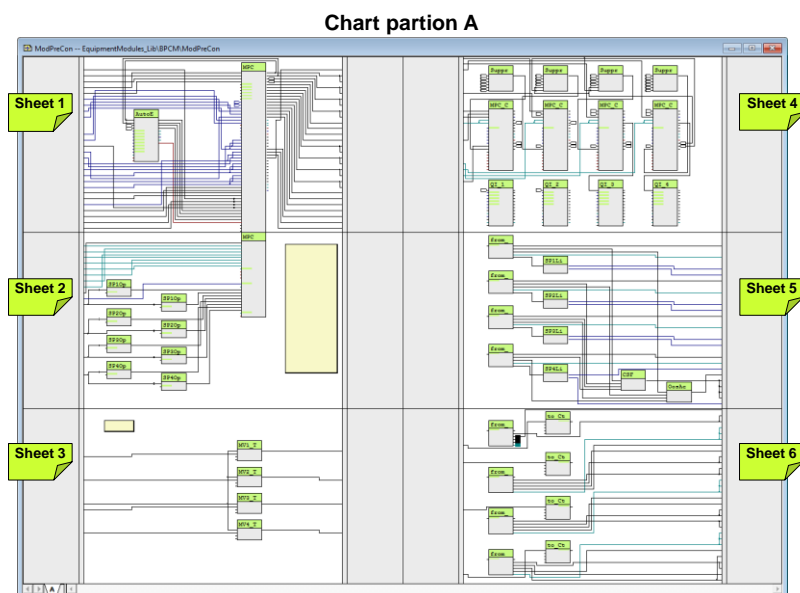
The instance receives the process variables with standardization from the "MonAn" process tags via "from\_Indicate\_x". The number of controlled variables is determined by activating options "Ctrl\_PV\_3" and "Ctrl\_PV\_4". It is not possible to deselect "Ctrl\_PV\_1" and "Ctrl\_PV\_2" and they correspond to the smallest configuration. Each "Ctrl\_PV\_x" option contains the monitoring of control performance, interface blocks for the process variable ("MonAn") and controller process tag as well as the setpoint tolerance limits and manipulated variable tracking.

Due to the complex control tasks (affected by up to four manipulated variables) and the required computing power, the multivariable controller is used by preference for slow control loops.

Examples of multivariable controllers include:

- Control of drying processes (product quality)
- Control of distillation columns (rectification)

#### Structure



#### Chart partition A

The following blocks are located on sheet 1:

- MPC ("ModPreCon"): Multivariable controller
- AutoExcitation ("AutoExc"): Process excitation signals for the MPC (during commissioning of the controller only)

Blocks for static operating point optimization of controlled variables of the MPC controller are located on sheet 2:

- SP1OptHiLim ("Add04"): Adaptation of the upper tolerance limit for SP1
- SP1OptLoLim ("Add04"): Adaptation of the lower tolerance limit for SP1
- SP2OptHiLim ("Add04"): Adaptation of the upper tolerance limit for SP2
- SP2OptLoLim ("Add04"): Adaptation of the lower tolerance limit for SP2
- SP3OptHiLim ("Add04"): Adaptation of the upper tolerance limit for SP3
- SP3OptLoLim ("Add04"): Adaptation of the lower tolerance limit for SP3
- SP4OptHiLim ("Add04"): Adaptation of the upper tolerance limit for SP4
- SP4OptLoLim ("Add04"): Adaptation of the lower tolerance limit for SP4

**NOTE**

In the case of operating point optimization, you do not specify an exact setpoint (e.g. SP1) for a controlled variable; rather, a tolerance range is specified. The associated command value (CV1) may be within this tolerance. Due to this tolerance definition, the controller works more flexibly and more economically, since it does not have to control continuously to a fixed value.

The following blocks are located on sheet 3:

- MV1\_TrkOn ("Or04"): Forced manipulated variable (MV1) for the MPC controller in the case of a hardware fault (CV\_Bad) or if cascade switching is interrupted between the MV1 PID controller and the slave controller
- MV2\_TrkOn ("Or04"): Forced manipulated variable (MV2) for the MPC controller in the case of a hardware fault (CV\_Bad) or if cascade switching is interrupted between the MV2 PID controller and the MV2 slave controller
- MV3\_TrkOn ("Or04"): Forced manipulated variable (MV3) for the MPC controller in the case of a hardware fault (CV\_Bad) or if cascade switching is interrupted between the MV3 PID controller and the MV3 slave controller
- MV4\_TrkOn ("Or04"): Forced manipulated variable (MV3) for the MPC controller in the case of a hardware fault (CV\_Bad) or if cascade switching is interrupted between the MV4 PID controller and the MV4 slave controller

The blocks below for monitoring and display of the control performance and the control deviation are located on sheet 4:

- Suppr\_CPM\_Calc\_1 ("Or04"): Suppression of CPI calculation and message if message suppression was caused at an "MPC\_CPM\_x" (CPI\_SuRoot = 1) or a warning is active due to low control performance (CPI\_WL\_Act = 1).
- Suppr\_CPM\_Calc\_2 ("Or04"): Suppression of CPI calculation and message if message suppression was caused at an "MPC\_CPM\_x" (CPI\_SuRoot = 1) or a warning is active due to low control performance (CPI\_WL\_Act = 1).
- Suppr\_CPM\_Calc\_3 ("Or04"): Suppression of CPI calculation and message if message suppression was caused at an "MPC\_CPM\_x" (CPI\_SuRoot = 1) or a warning is active due to low control performance (CPI\_WL\_Act = 1).
- Suppr\_CPM\_Calc\_4 ("Or04"): Suppression of CPI calculation and message if message suppression was caused at an "MPC\_CPM\_x" (CPI\_SuRoot = 1) or a warning is active due to low control performance (CPI\_WL\_Act = 1).
- MPC\_CPM\_1 ("ConPerMon"): Block for permanent monitoring of control performance (SP1Out, MV1 and CV1Out)
- MPC\_CPM\_2 ("ConPerMon"): Block for permanent monitoring of control performance (SP2Out, MV2 and CV2Out)
- MPC\_CPM\_3 ("ConPerMon"): Block for permanent monitoring of control performance (SP3Out, MV3 and CV3Out)
- MPC\_CPM\_4 ("ConPerMon"): Block for permanent monitoring of control performance (SP4Out, MV4 and CV4Out)
- QI\_1 ("MonAnL"): Display and limit monitoring of the average value of control deviation for the TimeWindow specified in "MPC\_CPM\_1"
- QI\_2 ("MonAnL"): Display and limit monitoring of the average value of control deviation for the TimeWindow specified in "MPC\_CPM\_2"
- QI\_3 ("MonAnL"): Display and limit monitoring of the average value of control deviation for the TimeWindow specified in "MPC\_CPM\_3"
- QI\_4 ("MonAnL"): Display and limit monitoring of the average value of control deviation for the TimeWindow specified in "MPC\_CPM\_4"

The following blocks are located on sheet 5:

- from\_Indicate\_1 ("ComStruOut"): Reception of signals (measured value, unit, scaling and messages) of the first process value to be controlled
- from\_Indicate\_2 ("ComStruOut"): Reception of signals (measured value, unit, scaling and messages) of the second process value to be controlled
- from\_Indicate\_3 ("ComStruOut"): Reception of signals (measured value, unit, scaling and messages) of the third process value to be controlled

- from\_Indicate\_4 ("ComStruOut"): Reception of signals (measured value, unit, scaling and messages) of the fourth process value to be controlled
- SPLim\_1 ("StruScIn"): Upper and lower setpoint limit of the first process value
- SPLim\_2 ("StruScIn"): Upper and lower setpoint limit of the second process value
- SPLim\_3 ("StruScIn"): Upper and lower setpoint limit of the third process value
- SPLim\_4 ("StruScIn"): Upper and lower setpoint limit of the fourth process value
- CSF ("Or04"): Formation of an OR output signal of the hardware faults of the channel blocks of the process values for tracking the respective controller
- OosAct ("Or04"): Formation of an OR output signal of the "OosAct" message of the channel blocks (field device is being maintained) of the controlled variables for the MPC

The link blocks below, which are used for rapid engineering, are located on sheet 6:

- from\_CTRL\_1 ("ComStruOu"): Reception of control commands of the lower level PID controller for the MPC controller parameters ("MV1ManHiLim", "MV1ManLoLim", and "MV1Trk") and the "MV1\_TrkOn" block.
- to\_CTRL\_1 ("ComStruIn"): Output of the manipulated variable as a setpoint to the lower-level PID controller.
- from\_CTRL\_2 ("ComStruOu"): Reception of control commands of the lower level PID controller for the MPC controller parameters ("MV2ManHiLim", "MV2ManLoLim", and "MV2Trk") and the "MV2\_TrkOn" block.
- to\_CTRL\_2 ("ComStruIn"): Output of the manipulated variable as a setpoint to the lower-level PID controller.
- from\_CTRL\_3 ("ComStruOu"): Reception of control commands of the lower level PID controller for the MPC controller parameters ("MV3ManHiLim", "MV3ManLoLim", and "MV3Trk") and the "MV3\_TrkOn" block.
- to\_CTRL\_3 ("ComStruIn"): Output of the manipulated variable as a setpoint to the lower-level PID controller.
- from\_CTRL\_4 ("ComStruOu"): Reception of control commands of the lower level PID controller for the MPC controller parameters ("MV4ManHiLim", "MV4ManLoLim", and "MV4Trk") and the "MV4\_TrkOn" block.
- to\_CTRL\_4 ("ComStruIn"): Output of the manipulated variable as a setpoint to the lower-level PID controller.

**NOTE**

The process value is made available to the MPC by linking the MonAn control module ("to\_Indicate" block) with the "from\_Indicate\_x" block.

## 4.3.2. Predictive controller for only one controlled variable

The "ModPreCon4Valve" CMT is used for fixed value controllers where the controlled variable is affected by one or more measurable disturbance variables, e.g. pH value control.

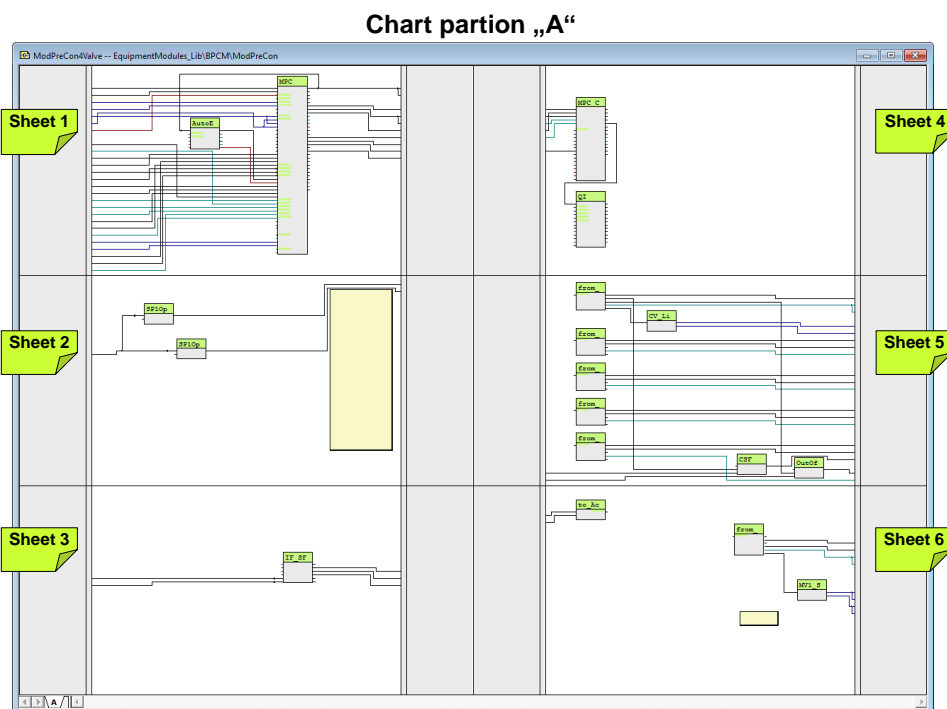
The MPC gets the units and standardization automatically from the connected interface blocks, from the controlled and manipulated variables, and from at least one disturbance variable.

**NOTE**

The number of disturbance variables is determined by activating option "Opt\_DVx" and interconnecting the respective process value. The disturbance variables are interconnected with the following MPC inputs:

- 1st disturbance variable at the DV1 input of the MPC (activated as standard)
- 2nd disturbance variable at the MV2Trk input of the MPC (optional)
- 3rd disturbance variable at the MV3Trk input of the MPC (optional)
- 4th disturbance variable at the MV4Trk input of the MPC (optional)

## Structure

**Chart partition A**

The following blocks are located on sheet 1:

- MPC ("ModPreCon"): Multivariable controller
- AutoExcitation ("AutoExc"): Process excitation signals for the predictive MPC (during commissioning of the controller only)

Blocks for static operating point optimization of the controlled variable of the MPC controller are located on sheet 2:

- SP1OptHiLim ("Add04"): Adaptation of the upper tolerance limit for SP1
- SP1OptLoLim ("Add04"): Adaptation of the lower tolerance limit for SP1

**NOTE**

In the case of operating point optimization, you do not specify an exact setpoint (e.g. SP1) for a controlled variable; rather, a tolerance range is specified. The associated command value (CV1) may be within this tolerance. Due to this tolerance definition, the controller works more flexibly and more economically, since it does not control continuously to a fixed value.

The blocks below for monitoring and display of the control performance and the control deviation are located on sheet 4:

- MPC\_CPM ("ConPerMon"): Block for permanent monitoring of control performance (SP1Out, MV1 and CV1Out)
- QI ("MonAnL"): Display and limit monitoring of the average value of control deviation for the TimeWindow specified in "MPC\_CPM"

The following blocks are located on sheet 5:

- from\_CV ("ComStruOut"): Receiving of signals (measured value, unit, scaling and messages) of the controlled variable
- CV\_Lim ("StruScIn"): Upper and lower setpoint limit of the controlled variable
- from\_DV1 ("ComStruOut"): Receiving of signals (measured value, CSF-signal and unit) of the first disturbance variable
- from\_DV2 ("ComStruOut"): Receiving of signals (measured value, CSF-signal and unit) of the second disturbance variable
- from\_DV3 ("ComStruOut"): Reception of signals (measured value, CSF-signal and unit) of the third disturbance variable
- from\_DV4 ("ComStruOut"): Reception of signals (measured value, CSF-signal and unit) of the fourth disturbance variable

- CSF ("Or04"): Formation of an OR output signal of the hardware faults of the controlled variable channel blocks and the control valve for tracking the manipulated variable
- OosAct ("Or04"): Formation of an OR output signal of the "OosAct" message of the channel blocks (field device is being maintained) of the controlled variables and the control valve for the MPC

**NOTE**

The process values of the controlled variable and the disturbance variables are made available to the MPC by linking the MonAn control modules ("to\_Indicate" block) with the "from\_CV", "from\_DVx" block.

The link blocks below, used for rapid engineering, are located on sheet 6.

- to\_Actor ("ComStruIn"): Transfer of the manipulated variable (MV1), and the locking status (OosAct) to the actuator.
- from\_Actor ("ComStruOu"): Reception of signals and standardization and unit of the actuator for the MPC (CSF, OosAct, ScaleOut, Unit).
- MV1\_Scale ("StruScIn"): Upper and lower manipulated variable limit for limiting the manipulated variable in the controller in manual and automatic modes.

## 4.4. "PIDCon" controller

The controller CMTs contain controller blocks, additional monitoring and interlock functions, interface blocks (master/actuator), and a link to sequential function charts.

The CMTs are pre-configured for different areas of application.

The following controller CMTs are available:

- "PIDCon" for standard PID controllers
- "PIDConRatio" for ratio controllers
- "PIDConSplitRange" for controllers with one manipulated variable and two actuators

### 4.4.1. Standard controller

The "PIDCon" CMT is used for fixed-value and cascade controllers and is a component from the Basic Control Modules (BCM). The detailed description of the you can find in the application example "Control Module (CM) Technology - Efficient Engineering with SIMATIC PCS 7" under the link:

<https://support.industry.siemens.com/cs/ww/en/view/109475748>

Examples of standard controllers include:

- Fill level controller with inflow and outflow
- Temperature control

## 4.4.2. Ratio controller

The "PIDConRatio" control module type is used for ratio controllers. Ratio controllers are composed of a flow controller (for the main component) and a flow controller for each additional component. The instance of "PIDConRatio" is used for the component that is to be added in a defined ratio, e.g. the blended component.

**NOTE** In "Plant View", you activate master/slave operation by selecting "Opt\_IF\_Master". After activation, the "to\_Master" and "from\_Master" link blocks are available.

Using variants, the corresponding channel block is selected or deselected based on measured value transfer.

In addition, it is possible to use options to activate further functions without configuration at the CMT instance.

Variants and options are listed and described below.

### Variant 1: Controller for analog measurement and manipulated variable (4-20 mA)

Variant 1 is activated by selecting functions PV\_In and Opt\_PV\_Scale at the instance.

### Variant 2: Controller for thermocouples

This variant is used for thermocouples that are connected to an analog input module for temperature measurement.

Variant 2 is activated by selecting function PV\_TE\_In at the instance.

**NOTE** Scaling on the channel block has already been preset for the range 0 to 1. You must carry out process value scaling at input "NormPV" of display block "C".

### Variant 3: Controller for digital measurement (field bus)

This variant is used if you are using measuring devices with Profibus PA or Fieldbus Foundation (FF).

Variant 3 is activated by selecting functions PV\_Fb\_In and Opt\_PV\_Scale on the instance.

### Variant 4: Controller for software signal

Variant 4 is the default setting without additional functions activated at the instance. In this variant, the process value is obtained by direct CFC connection from existing process tags. Using the optional DeltaCalc function, it is possible to apply difference measurement for the controlled variable.

Optional functions for all variants:

- PV\_Scale#: Standardization of the process value including the channel block
- CPM: Monitoring of the control quality
- IF\_Master#: Connection to a master controller (cascade)
- PV\_DeltaCalc#: Differentiation
- Interlock: Interlocking block

The figure below lists the available options.

PIDConRatio (CMT Master Data Library)	PV_Scale#	CPM	IF_Master#	PV_DeltaCalc	Interlock	PV_In	PV_Fb_In	PV_TE_In	Description
	Function			Channel block					
PIDConRatio_Std	x	o	o	o	o	x			Standard display (analog)
PIDConRatio_TE		o	o	o	o			x	Measured value display for thermocouples
PIDConRatio_Fb	x	o	o	o	o		x		Measured value display fieldbus
PIDConRatio_SW	o	o	o	o	o				Program logic without channel blocks

x = Selecting a variant      o = Selectable functions

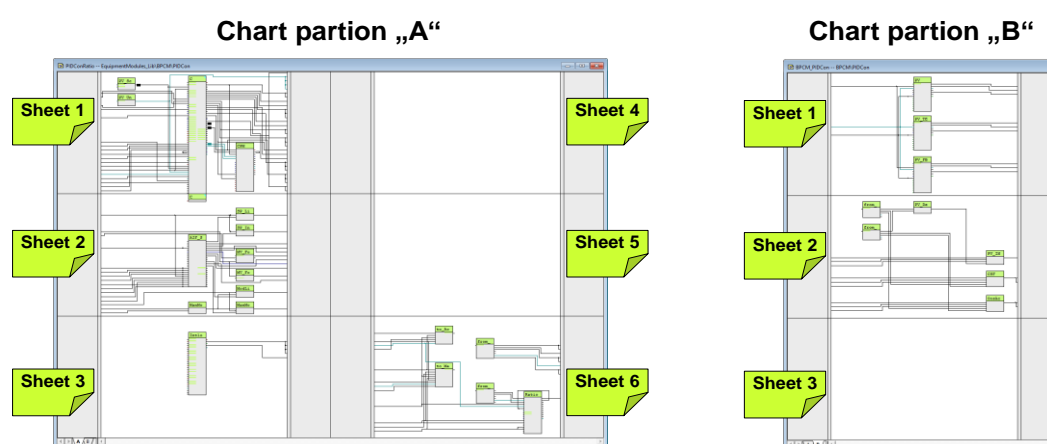
Examples of ratio controllers include:

- Blending control of liquids or gases with a defined mixing ratio
- Air feed in a defined ratio to fuel gas feed for gas burners

**NOTICE** When using the Plant Automation Accelerator (PAA) V2.1, the variant "PV\_Scale#" should not be used. The scaling is set in PAA at the respective signal and adopted by the appropriate "Scale" input when exporting to SIMATIC PCS 7.

**NOTE** In "plant view", you activate master/slave operation by selecting "IF\_Master#". After activation, the "to\_Master" and "from\_Master" link blocks are available.

## Structure



### Chart partition "A"

The following blocks are located on sheet 1:

- PV\_Scale: Standardization of the process value for a channel block and measured value display
- PV\_Unit: Standardization of the unit for a channel block and displaying measured values
- C ("PIDConL"): PID controller
- CPM ("ConPerMon"): Block for permanent monitoring of control quality  
The outputs, operating mode, setpoint, actual value and manipulated variable of the PID controller are interconnected with the CPM block

The following blocks are located on sheet 2:

- AIF\_SFC ("ConnPID"): A free block for SFC linking (not a component of the APL or the standard library)
- Logic blocks for selecting the operating mode and for interlocking
  - SP\_LiOp ("Or04"): Setpoint source internal/external
  - SP\_IntLi ("Or04"): Internal setpoint via interconnection
  - MV\_Forced ("SelA02In"): Forced manipulated variable with selection ("In1" undefined, "In2" SFC link)
  - MV\_ForOn ("Or04"): Activates forced manipulated variable "In2" (MV\_Forced) on the PID controller
  - ManModOpLi ("Or04"): Formation of an OR output signal from field device in maintenance (channel blocks PV and MV) and invalid process value (channel block PV in chart partition "B", Sheet 1.)
  - ModLiOp ("Or04"): Operating mode selection between operator and interconnection or SFC
  - ManModLi ("Or04"): Manual mode via interconnection or SFC (controlled via ModLiOp = 1)

Using the SFC link, data that is relevant to production is transferred to the PID controlling via the logic blocks. In addition, channel blocks and the interlocking block (chart partition "A", Sheet 3) affect the output signals of the logic blocks.

Sheet 3 contains the "Intlock" interlocking module, which combines signals for standardized interlocking with the option of displaying them on the OS.



The link blocks below, used for rapid engineering, are located on sheet 6.

- to\_Actor\_Slave ("ComStruIn"): Transfer of the manipulated variable (MV), setpoint value (SP), process value (PV), and the locking status to the actuator or slave (slave in the case of cascade control)
- from\_Actor\_Slave ("ComStruOu"): Reception of the actuating signal feedback (Rbk), the message with invalid process values, and field device maintenance of channel blocks MV and Rbk, of the out unit and scaling of the actuating display and travel range (ScaleOut) of the actuator or slave (slave in the case of cascade control)
- to\_Master ("ComStruIn"): The communication block forms a structure consisting of outputs (setpoint, block is "out of service" message, message for cascade switching, process value), of the PID controller, of the CSF block (message of the channel blocks in the case of an invalid process value), and of channel blocks PV and MV (unit and scaling of the process value).
- from\_Master ("ComStruOu"): The communication block receives from the controller process tag of the main component the signals of the CSF block and the setpoint of the PID controller that are relevant to interlocking.
- Ratio ("Ratio"): The block calculates the setpoint of the slave controller from the setpoint of the master PID controller and the specified ratio.

### Chart partition "B"

The channel blocks are located on sheet 1:

- PV ("Pcs7AnIn"): Channel block for signal processing of an analog measured value, e.g. 0/4 to 20mA
- PV\_TE ("Pcs7AnIn"): Channel block for signal processing of a resistance thermometer
- PV\_FB ("FBAnIn"): Channel block for signal processing of a digitized process value (PA or FF processing unit)

The modules for the difference display are located on sheet 2:

- PV\_DeltaCalc ("Sub02"): Formation of a difference value from two process values, e.g. differential pressure
- FromDeltaIn1: Input 1 for the difference value
- FromDeltaIn2: Input 2 for the difference value
- PV\_IN ("Add08"): Merging the "PV\_In" signals (analog process value)
- CSF ("Or04"): Grouping of the "Bad" signals (invalid process value) and reporting to the motor block and the Permit group block
- OosAct ("Or04"): Grouping of the "OosAct" signals (device being maintained) and reporting to the motor block

#### NOTE

If a thermocouple is used, you must carry out scaling at channel block "PV\_TE" measured value display in addition to scaling at block PV\_Scale (process value scaling).

#### NOTICE

The channel block for the thermocouple has already been preset for the range 0.0 to 1.0.

On sheet 2, the system additionally acquires the messages of the valve process tag channel block at blocks CSF and OosAct and transfers them to the controller.

In the case of a positive "OosAct" signal, the controller switches to manual mode.

### 4.4.3. Split range controller

The "PIDConSplitRange" control module type is used for controllers where one manipulated variable controls several actuators (with a limited effective range and possibly the opposite direction of control action), i.e. the manipulated variable is split to several actuators.

**NOTE** In "Plant View", you activate master/slave operation by selecting "Opt\_IF\_Master". After activation, the "to\_Master" and "from\_Master" link blocks are available.

Using variants, the corresponding channel block is selected or deselected based on measured value transfer.

In addition, it is possible to use options to activate further functions without configuration at the CMT instance.

Variants and options are listed and described below.

#### Variant 1: Controller for analog measurement and manipulated variable (4-20 mA)

Variant 1 is activated by selecting functions PV\_In and Opt\_PV\_Scale at the instance.

#### Variant 2: Controller for thermocouples

This variant is used for thermocouples that are connected to an analog input module for temperature measurement.

Variant 2 is activated by selecting function PV\_TE\_In at the instance.

**NOTE** Scaling on the channel block has already been preset for the range 0 to 1. You must carry out process value scaling at input "NormPV" of display block "C".

#### Variant 3: Controller for digital measurement (field bus)

This variant is used if you are using measuring devices with Profibus PA or Fieldbus Foundation (FF).

Variant 3 is activated by selecting functions PV\_Fb\_In and Opt\_PV\_Scale on the instance.

#### Variant 4: Controller for software signal

Variant 4 is the default setting without additional functions activated at the instance. In this variant, the process value is obtained by direct CFC connection from existing process tags. Using the optional DeltaCalc function, it is possible to apply difference measurement for the controlled variable.

Optional functions for all variants:

- PV\_Scale#: Standardization of the process value including the channel block
- CPM: Monitoring of the control quality
- IF\_Master#: Connection to a master controller (cascade)
- PV\_DeltaCalc#: Differentiation
- Interlock: Interlocking block

The figure below lists the available options.

PIDConSplitRange (CMT Master Data library)		PV_Scale#	CPM	IF_Master#	PV_DeltaCalc#	Interlock	PV_In	PV_Fb_In	PV_TE_In	
Variants	Function	Channel block			Description					
PIDConSplitRange_Std	x	o	o	o	o	x				Standard display (analog)
PIDConSplitRange_TE		o	o	o	o			x		Measured value display for thermocouples
PIDConSplitRange_Fb	x	o	o	o	o		x			Measured value display fieldbus
PIDConSplitRange_SW	o	o	o	o	o					Program logic without channel blocks

x = Selecting a variant      o = Selectable functions

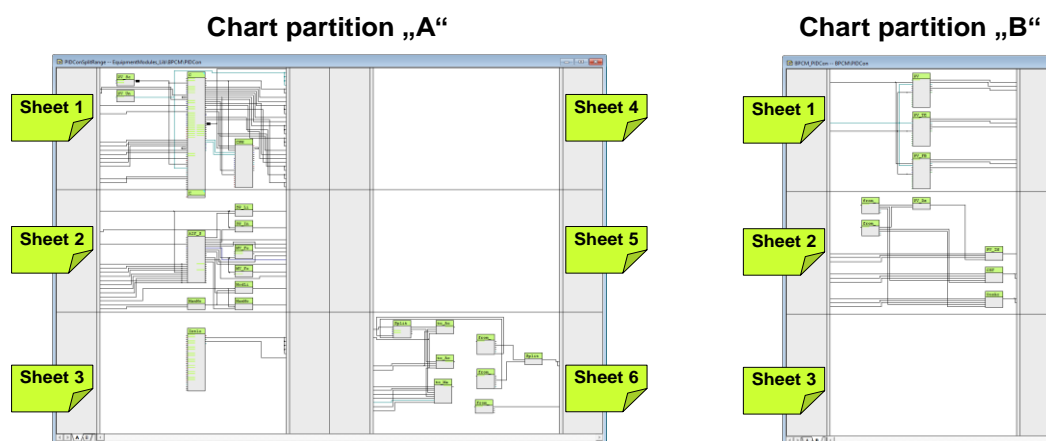
Examples of split-range controllers with opposite direction of control action include:

- Temperature controllers with separate actuators for heating and cooling, e.g. valves for heating steam and cooling water, or electric heating and fan cooling.
- Pressure control with separate valves for gas feed and purge

Moreover, there are split range applications with several actuators with the same direction of action (that individually would not be strong enough), e.g.

- Oxygen control in bio fermenters via air feed and stirrer speed.
- Oxygen control in wastewater treatment plants via several compressors.

## Structure



The control module type is preconfigured for the following setpoint range:

- Manipulated variable 0 to 100 (from the controller)
- Manipulated variable 50 to 100 corresponds to travel range 0 to 100 with actuator 1
- Manipulated variable 50 corresponds to the neutral position, i.e. both actuators are closed
- Travel range 0 to 50 corresponds to travel range 100 to 0 with actuator 2

## Chart partition "A"

The following blocks are located on sheet 1:

- PV\_Scale: Standardization of the process value for a channel block and measured value display
- PV\_Unit: Standardization of the unit for a channel block and displaying measured values
- C ("PIDConL"): PID controller
- CPM ("ConPerMon"): Block for permanent monitoring of control quality  
The outputs, operating mode, setpoint, actual value and manipulated variable of the PID controller are interconnected with the CPM block

The following blocks are located on sheet 2:

- AIF\_SFC ("ConnPID"): A free block for SFC linking (not a component of the APL or the standard library)
- Logic blocks for selecting the operating mode and for interlocking
  - SP\_LiOp ("Or04"): Setpoint source internal/external
  - SP\_IntLi ("Or04"): Internal setpoint via interconnection
  - MV\_Forced ("SelA02In"): Forced manipulated variable with selection ("In1" undefined, "In2" SFC link)
  - MV\_ForOn ("Or04"): Activates forced manipulated variable "In2" (MV\_Forced) on the PID controller
  - ManModOpLi ("Or04"): Formation of an OR output signal from field device in maintenance (channel blocks PV and MV) and invalid process value (channel block PV in chart partition "B", Sheet 1.)
  - ModLiOp ("Or04"): Operating mode selection between operator and interconnection or SFC
  - ManModLi ("Or04"): Manual mode via interconnection or SFC (controlled via ModLiOp = 1)

Using the SFC link, data that is relevant to production is transferred to the PID controlling via the logic blocks. In addition, channel blocks and the interlocking block (chart partition "A", Sheet 3) affect the output signals of the logic blocks.

Sheet 3 contains the "Intlock" interlocking module, which combines signals for standardized interlocking with the option of displaying them on the OS.

The link blocks below, used for rapid engineering, are located on sheet 6.

- to\_Actor\_Slave ("ComStruIn"): Transfer of the manipulated variable (MV), setpoint value (SP), process value (PV), and the locking status to the actuator or slave (slave in the case of cascade control)
- from\_Actor\_Slave ("ComStruOu"): Reception of the actuating signal feedback (Rbk), the message with invalid process values, and field device maintenance of channel blocks MV and Rbk, of the out unit and scaling of the actuating display and travel range (ScaleOut) of the actuator or slave (slave in the case of cascade control)
- to\_Master ("ComStruIn"): The communication block forms a structure consisting of outputs (setpoint, block is "out of service" message, message for cascade switching, process value), of the PID controller, of the CSF block (message of the channel blocks in the case of an invalid process value), and of channel blocks PV and MV (unit and scaling of the process value).
- from\_Master ("ComStruOu"): The communication block receives from the controller process tag of the main component the signals of the CSF block and the setpoint of the PID controller that are relevant to interlocking.
- SplitRange ("SplRange"): block to split the manipulated variable MV from the PID controller. The segmentation is based on the set parameters.
- to\_Actor\_Slave2 ("ComStruIn"): Transfer of the manipulated variable (MV), setpoint value (SP), process value (PV), and the locking status to the actuator or slave (slave in the case of cascade control)
- from\_Actor\_Slave2 ("ComStruOu"): Reception of the actuating signal feedback (Rbk), the message with invalid process values, and field device maintenance of channel blocks MV and Rbk, of the out unit and scaling of the actuating display and travel range (ScaleOut) of the actuator or slave (slave in the case of cascade control)
- SplitRangeCut ("Or04"): Grouping of the disconnect signals from the cascaded valves to the controller.

### Chart partition "B"

The channel blocks are located on sheet 1:

- PV ("Pcs7AnIn"): Channel block for signal processing of an analog measured value, e.g. 0/4 to 20mA
- PV\_TE ("Pcs7AnIn"): Channel block for signal processing of a resistance thermometer
- PV\_FB ("FBAnIn"): Channel block for signal processing of a digitized process value (PA or FF processing unit)

The modules for the difference display are located on sheet 2:

- PV\_DeltaCalc ("Sub02"): Formation of a difference value from two process values, e.g. differential pressure
- FromDeltaIn1: Input 1 for the difference value
- FromDeltaIn2: Input 2 for the difference value
- PV\_IN ("Add08"): Merging the "PV\_In" signals (analog process value)
- CSF ("Or04"): Grouping of the "Bad" signals (invalid process value) and reporting to the motor block and the Permit group block
- OosAct ("Or04"): Grouping of the "OosAct" signals (device being maintained) and reporting to the motor block

#### NOTE

If a thermocouple is used, you must carry out scaling at channel block "PV\_TE" measured value display in addition to scaling at block PV\_Scale (process value scaling).

#### NOTICE

The channel block for the thermocouple has already been preset for the range 0.0 to 1.0.

On sheet 2, the system additionally acquires the messages of the valve process tag channel block at blocks CSF and OosAct and transfers them to the controller.

In the case of a positive "OosAct" signal, the controller switches to manual mode.

# 5. Equipment Modules

In this chapter, you will find all the relevant information for each equipment module including specific properties. The structure and basic functionality of the control module types that are used are described in Chapter 4 "[Control Module](#)".

The following equipment modules are described below:

- "Level-control"
- Buffer level control with feedforward disturbance compensation "Buffer-Control"
- "Split-Range-Pressure" control
- "Ratio-Control"
- "Split-Range-Temperature" control
- pH value control using the "pH-Control-Std" standard controller
- pH value control using the "pH-Control-MPC" model predictive controller
- Temperature cascade control via slave flow control loop "Temperature-Flow-Cascade"
- Coarse-/Finestream control using the "Stream-Control"
- Gradient limits in actuators "Gradient-Limit"

**NOTE**

Below, we will use the designations CM for control module and CMT for control module type.

# 5.1. "Level-Control" in process plants

## Introduction

Depending on the tasks that a container (e.g. vessel, tank, reactor) has to fulfill in a process plant, there are different objectives for a level controller. The two following control strategies are the most common in process industry:

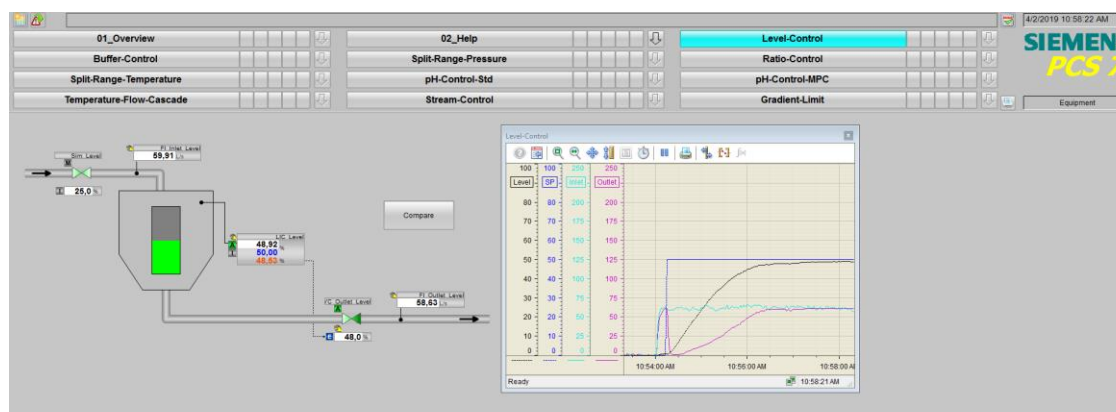
1. Keeping a level as close as possible to a specified setpoint, e.g. in a reactor or the sump of a column. This is necessary if the level affects chemical reactions or separation processes, i.e. it is significant to the process. Fluctuations in the inflow are compensated via variation of outflow to keep the level constant.
2. Use a container (e.g. a tank) as a buffer to achieve an inflow or outflow that is as uniform as possible. In this context, the system does not maintain a fixed level value exactly at the setpoint; the level just has to stay within permissible limits. This task is called "buffering controller" and characterizes the majority of industrial applications.

## 5.1.1. Exact level control

In the case of exact level control, input materials are fed via inlet lines to a tank and the mixture is removed via an outlet. The controller responds to deviations in the fill level (caused by differences between the amount flowing in and out) and compensates for them by either decreasing or increasing inflow or outflow.

For exact control of fill levels, a standard design with the PID tuner makes sense. In this context, you should be aware that most fill level processes have integrating behavior (e.g. outflow as a manipulated variable). In many cases, a proportional-only controller (without integral action) is adequate, which harmonizes more easily with the integrating process dynamics but shows permanent control errors if there are disturbances in the inflow. If the valve characteristic curve is non-linear, it is recommended in practice to use a cascade structure. The master controller regulates the fill level via specification of setpoints for the slave (out)flow controller, provided flow measurement at the outflow is available.

In the example below, level control is performed by directly manipulating the outlet valve, i.e. without slave flow controller.

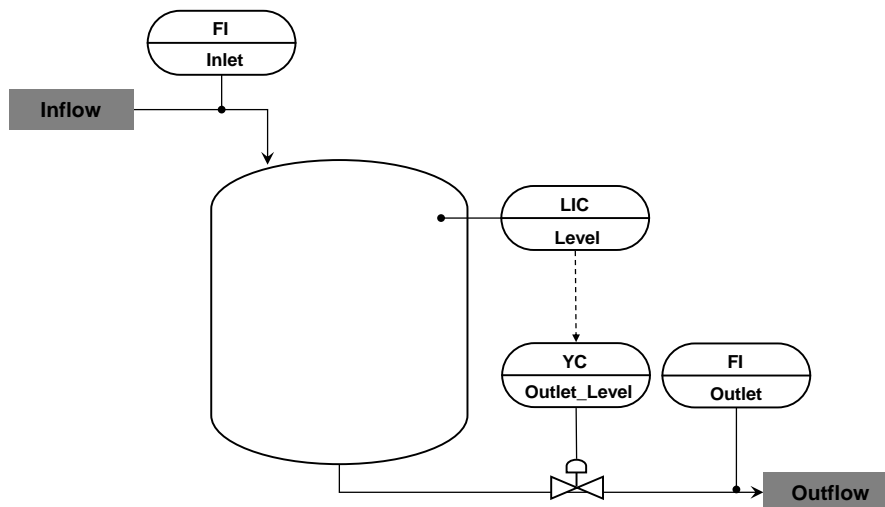


**Overview**

Below, the structure in the P&ID schematic is shown and all of the CMs and the simulation of the equipment module are described.

**P&I Diagram**

The P&ID below symbolically represents all of the components, such as field devices and containers relevant to operation.



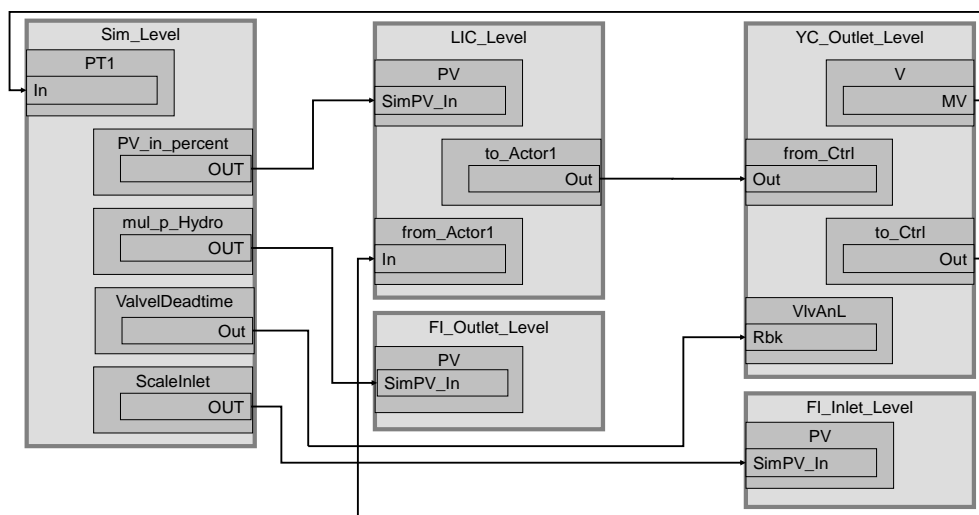
**CM and variants**

The "Level Control" equipment module consists of four connected CMs and one simulation chart. The fill level of a container is simulated in the "Sim\_Level" simulation chart with the help of a non-linear model. In addition, the response of the valve is simulated in this chart, which leads to a more realistic description of dynamic valve behavior. In the "Sim\_Level" simulation chart, the inflow is simulated with the help of a valve module and the valve position provided for disturbance compensation is added.

The following table provides an overview of the CMs of the equipment module including the associated CMTs.

CM	CMT	Selected variants	Description
FI_Inlet_Level	"MonAn"	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale#</li> </ul>	Display of container inlet
FI_Outlet_Level	"MonAn"	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale#</li> </ul>	Display of container discharge
LIC_Level	"PIDCon"	<ul style="list-style-type: none"> <li>• CPM</li> <li>• PV</li> <li>• PV_Scale#</li> </ul>	Level control of a container
YC_Outlet_Level	"ValAn"	<ul style="list-style-type: none"> <li>• GI</li> <li>• Intlock</li> <li>• IF_Ctrl#</li> <li>• MV_Scale#</li> <li>• YC</li> </ul>	Outlet valve for container discharge with safety position to prevent overflow

In the figure below, the structure with the cross-chart interconnections is shown in simplified form.



Control "LIC\_Level" acquires the fill level of the container ("Sim\_Level" simulation chart) and regulates it using "YC\_Outlet\_Level" control valve. In addition, the two process tags "FI\_Outlet\_Level" and "FI\_Inlet\_Level" serve the purpose of displaying inflow and discharge in the OS.

### Structure and parameterization

#### "Sim\_Level" simulation

The structure and the parameterization of the "Sim\_Level" simulation used is explained in Section [5.1.3](#).

#### LIC\_Level

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Unit	In	1342	Process value unit in %
C	NegGain		Activation of negative gain, since the controller is used for the outflow
C	Gain	2	Controller gain
C	TI	111.96	Controller lag
C	PV_AH_Li	95.0	Upper alarm limit for the process value
C	PV_AH_En	1	Enable upper alarm limit
C	PV_AH_Ac		Interconnection to the outlet valve (LIC_Level\to_Actor_Slave.BoStru3)
IF_SFC	SP_Ext		Connection for operator setpoint input for comparison (Compare\SP_Level.PV_In)
to_Actor_Slave	BoStru3		Interconnection to PID controller (LIC_Level\C.PV_AH_Ac)
to_Actor_Slave	Out		Interconnection to the valve (YC_Outlet_Level\from_Ctrl.In)
from_Actor_Slave	In		Interconnection to the valve (YC_Outlet_Level\to_Ctrl.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_Level\PV_in_percent.Out)



### YC\_Outlet\_Level

The instance has the following parameterization.

Block	Connection	Value	Use
V	MV		Interconnection to the valve simulation (Sim_Level\PT1.In)
V	SafePos	1	Safety position is open status
V	Monitor	1	Display of Checkback signal in the OS
from_Ctrl	In		Interconnection to the controller (LIC_Level\to_Actor_Slave.Out)
from_Ctrl	BoStru3		Interconnection to the Interlock (YC_Outlet_Level\Intlock.In1)
to_Ctrl	Out		Interconnection to the controller (LIC_Level\to_Actor_Slave.In)
MV_Out	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)
Intlock	InvIn01	1	Inversion of Input 01
Intlock	Logic	OR	OR input interconnection

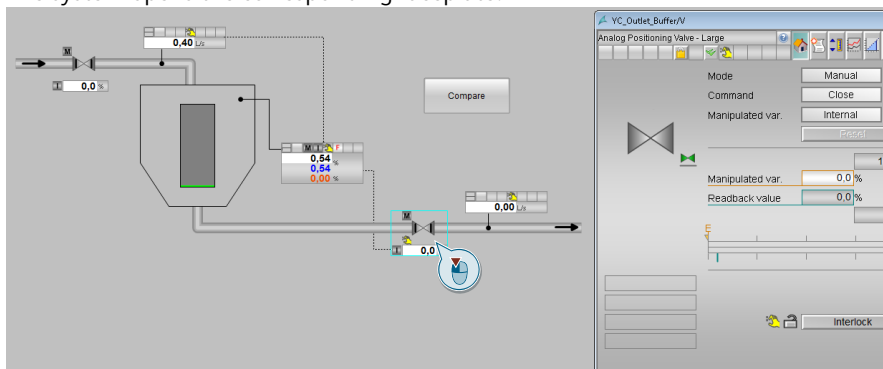
### Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

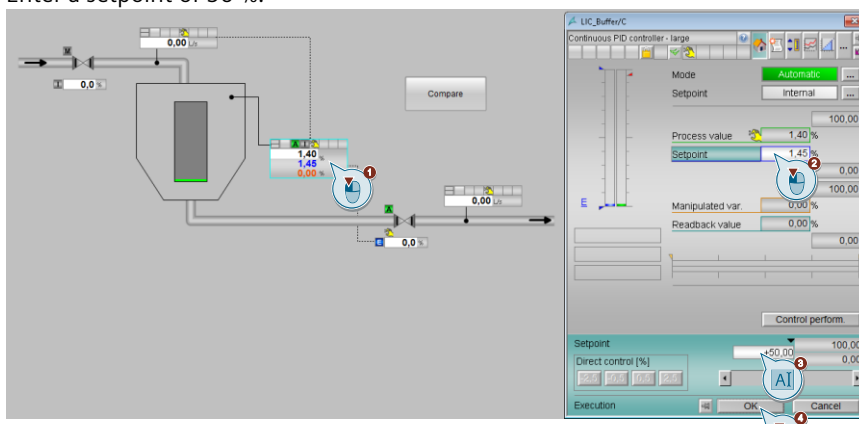
For commissioning, proceed as follows:

1. Click on the symbol display of the "YC\_Outlet\_Level" valve.

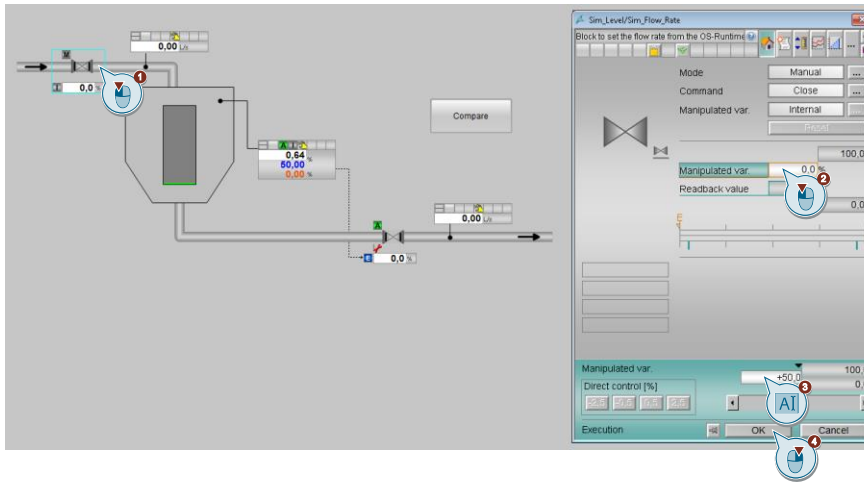
The system opens the corresponding faceplate.



2. In the faceplate, change the operating mode to "Automatic".
3. Switch to controller "LIC\_Level" and change the operating mode of the controller to "Automatic".
4. Enter a setpoint of 50 %.

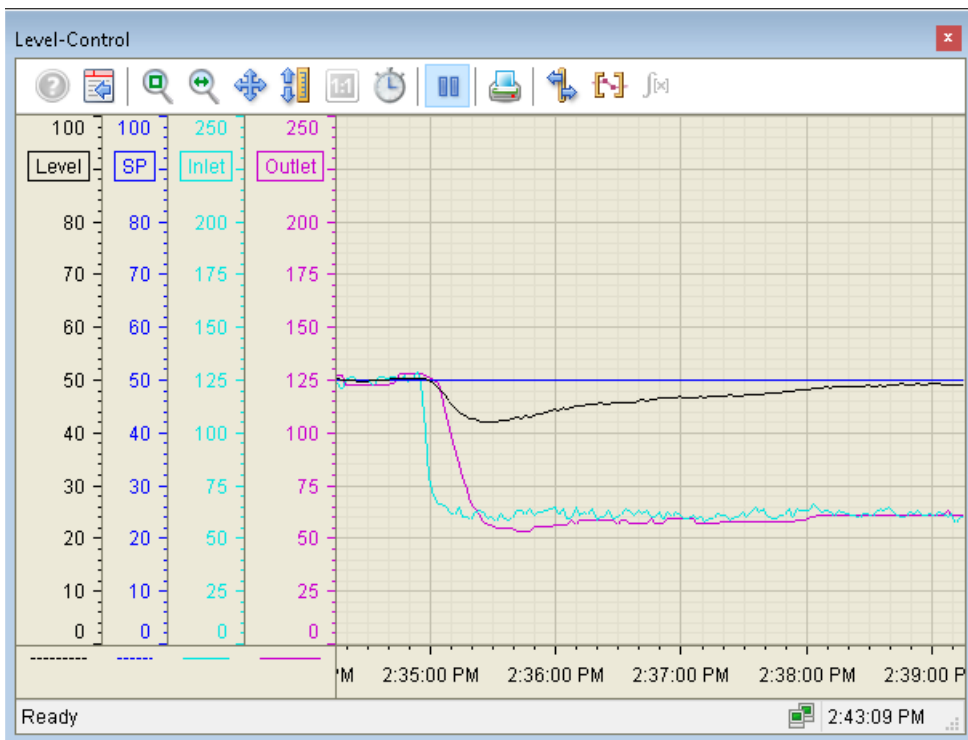


- Switch to "Sim\_Level/Sim\_Flow\_Rate" valve and change the setpoint to 50 %



- Wait for about 3 minutes and enter a new setpoint of 25 % for the "Sim\_Level/Sim\_Flow\_Rate" valve.
- Close the faceplate and observe the plotter for about two minutes until the new setpoint has been reached again.
- Then click on the "Start/Stop" icon on the toolbar of the OnlineTrendControl.

## Evaluation



After the inflow reduction, the level drops below the setpoint. The controller observes the level change and then reduces the setpoint of the discharge valve until the level once again reaches the setpoint. Control towards the setpoint, however, causes permanent fluctuations in the manipulated variable for the discharge valve.

## 5.1.2. Buffer level control with feedforward disturbance compensation "Buffer-Control"

In process plants, tanks are often employed as buffer containers. An exact level control is not necessary provided the level remains within defined limits. Instead, the controller has to work with as few interventions as possible. This reduces wear on the valves and at the same time reduces resource consumption (compressed air, etc.). In some applications, the primary aim is to achieve an outflow of the container that is as even as possible, such that subsequent apparatuses receive an inflow which is as even as possible. Common controller design methods (e.g. PI control with deadband) deliver less-than-satisfactory results, because the uncontrolled process is not asymptotically stable. Typically, there will be oscillations at the edge or between high and low limit of the deadband.

In this example, we will show the advantages of buffer control including feedforward disturbance compensation. Feedforward control reacts faster to disturbances and largely prevents leaving the dead zone. For this, any measured variable representative of the tank inflow, for example a flow measurement, a valve position, or a pump rotational speed, is connected as a feedforward disturbance compensation signal with its own deadband. The deadband of the buffer controller is activated or deactivated dynamically.

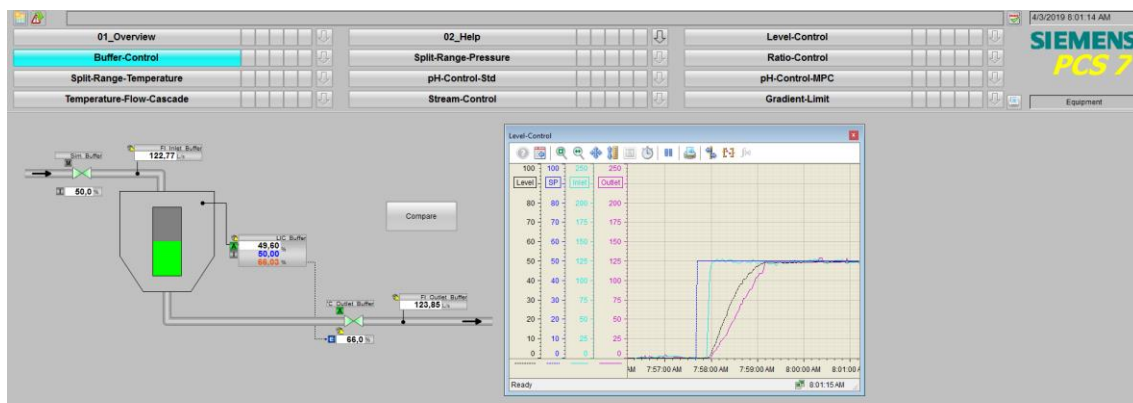
### Mode of operation

In the case of a closed-loop control with deadband, the manipulated variable is not changed as long as the controlled variable moves within the parameterized limits of the deadband. Only if the values leave the deadband, the feedback controller and consequently the final actuator become active.

If the controller is active, the deadband is dynamically switched off until the controlled variable is again in the center of the deadband. This prevents a permanent fluctuation at the edge of the deadband.

### NOTE

The actuator activity can be further reduced by means of low-pass filtering of the disturbance variable. This has no effect on the stability of the control loop because the low-pass filter is only in the feedforward variable and not in the feedback path of the closed control loop. In addition, the feedforward control is provided with its own deadband in order to further reduce actuator activity.



### Controller design

In context of a buffer control task, the required behavior is different from exact level control. In buffer control, the tank volume is used selectively to compensate for inflow fluctuations. Two options are available when doing this:

- The fill level is not measured continuously at all; rather, the minimum and maximum limits are monitored by binary (e.g. capacitive) fill level switches. Continuous control is not used for this solution; rather, discrete-event control is used, i.e. a binary signal is used to close the inflow or outflow.
- Controller tuning is purposefully set slower. Within the scope of the specification, the maximum permissible deviation  $\Delta h_{\max}$  of the fill level from the setpoint is defined, as well as the maximum height  $d_{\max}$  of inflow step disturbances to be expected. With regard to permanent control deviation, the gain of a P controller must be defined as greater than  $\text{Gain} = d_{\max} / \Delta h_{\max}$ . You can also set up a PI controller such that the maximum deviation of fill level after step disturbance is less than  $d_{\max}$ . In the Dechema Seminar entitled "Process Controls – From the Basics to Advanced Control" ([www.dechema.de](http://www.dechema.de)), the formulas below are recommended:

- $\text{GainEff} = 0.7358 \cdot d_{\max} / \Delta h_{\max}$
- $T_i = 5.4366 / K_i \cdot \Delta h_{\max} / d_{\max}$

**NOTE**

The physical controller gain is in units MV\_Unit/PV\_Unit. In case of normalization (NormPV ≠ NormMV), gain must be converted according to the following formula:

$$\text{Gain} = \text{GainEff} * (\text{NormPV.High} - \text{NormPV.Low}) / (\text{NormMV.High} - \text{NormMV.Low})$$

It is possible to determine the integration constant  $K_i$  of the controlled process in the unit PV\_Unit/s using the PID tuner. You can find the integration constants at "Gain" in the "Process parameter" sector.

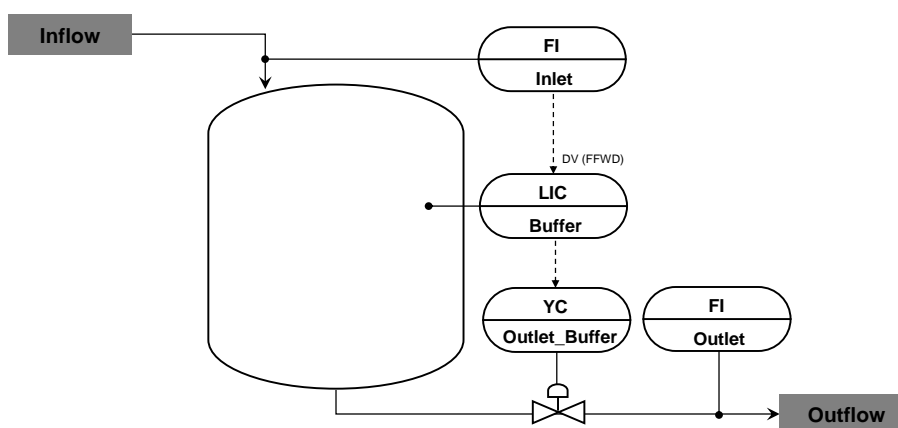
**Controller Optimization Step 7: Results and selection of the controller**

Process parameters		Controller parameters	
PTn model, order:	1	Proportional gain:	
Gain:	-6.084 1/s	Integration time:	
Time constant:	8.067 s	Derivative time:	
Model fit:	97.142 %		
Time lag:	8.067 s		
Max. sampling time:	0.807 s		

- In order to avoid permanent control deviations, the proportional-only controller is enhanced with feedforward disturbance compensation. This alternative is implemented in the template. In this case, the formulas with respect to disturbance amplitude mentioned in the above paragraph are not relevant. The controller can be designed with any standard approach considering stability and control performance, e.g. with PCS 7 PID-Tuner. During application of PID-Tuner take care that the disturbance variable stays as even as possible during data logging for step testing. After tuning, the level controller is temporarily run without deadband to verify loop dynamics, before activating deadband in order to smooth outflow variations.

**Overview****P&I Diagram**

The P&I diagram below symbolically represents all of the components, such as field devices and tanks relevant to operation.

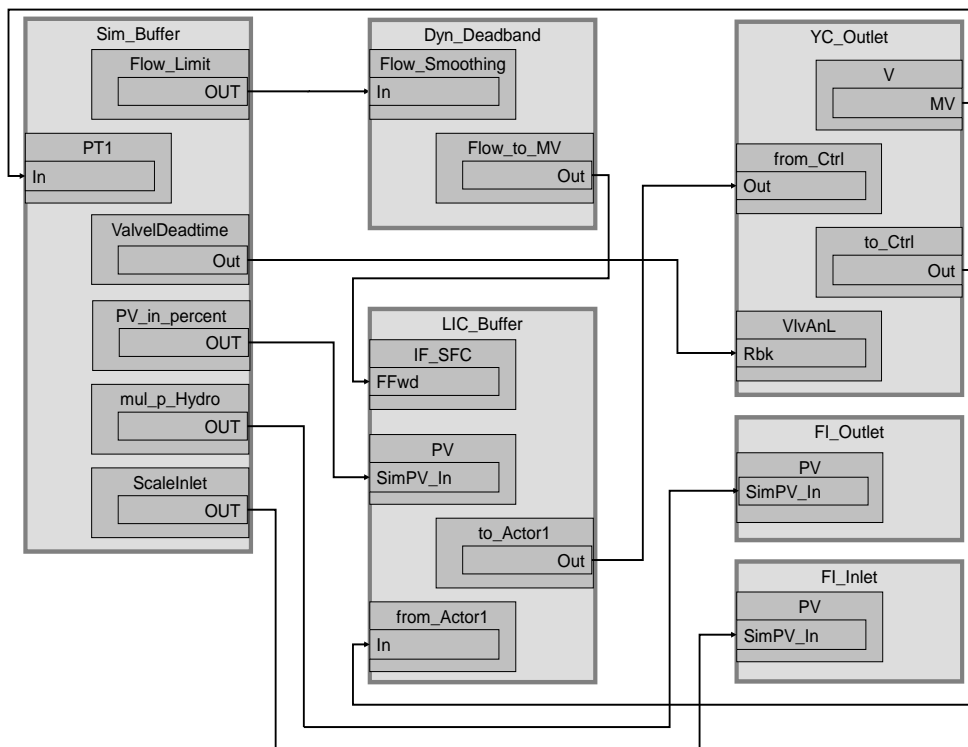
**CM and variants**

The "BufferControl" equipment module consists of three connected control modules, a CFC chart for the dynamic deadband of the feedforward disturbance compensation and a simulation plan. The level of a container is simulated in the "Sim\_Buffer" simulation chart with the help of a non-linear model. In addition, the dynamic response of the valve is simulated in this chart, which leads to a more realistic model of valve behavior. In the "Sim\_Buffer" simulation chart, the inflow is simulated with the help of a valve module and valve position is provided as disturbance variable.

The following table provides an overview of the components of the equipment module including the associated control modules.

CM	CM	Selected variants	Description
FI_Inlet_Buffer	"MonAn"	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale#</li> </ul>	Display of the container inlet
FI_Outlet_Buffer	"MonAn"	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale#</li> </ul>	Display of container discharge
LIC_Buffer	"Ctrl"	<ul style="list-style-type: none"> <li>CPM</li> <li>PV</li> <li>PV_Scale#</li> </ul>	Level control
YC_Outlet_Buffer	"ValAn"	<ul style="list-style-type: none"> <li>GI</li> <li>Intlock</li> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>YC</li> </ul>	Outlet valve for container discharge with safety position to prevent overflow

In the figure below, the structure with the cross-chart interconnections is shown in simplified form.



Control "LIC\_Buffer" acquires the fill level of the container and regulates it using "YC\_Outlet\_Buffer" control valve. In addition the "Sim\_Buffer" transmits the disturbance variable – the inflow into the container – to the "LIC\_Buffer" process tag which adds the "disturbance variable" to the manipulated variable of the controller. In addition, the simulation generates from the valve state the inlet and outlet of the tank, which visualize over the both display monitors "FI\_Inlet" and "FI\_Outlet".

**Structure and parameterization****Sim\_Buffer**

The structure and the parameterization of the "Sim\_Buffer" simulation used is explained in Section [5.1.3](#).

**LIC\_Buffer**

The instance has the following parameterization.

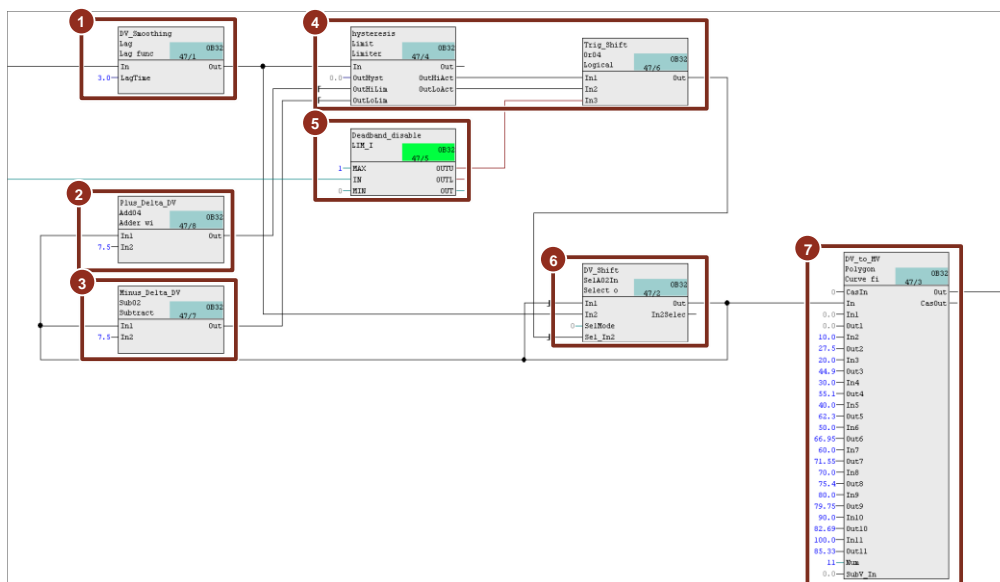
Block	Connection	Value	Use
PV_Scale	HiScale	100.0	Scaling of the process value upper limit
PV_Unit	In	1342	Process value unit in %
C	NegGain	1	Activation of negative gain, since the controller is used for the outflow
C	Gain	0.8	Controller gain
C	TI	0.0	Controller lag
C	DeadBand	15.0	Deadband
C	SP_InHiLim	100.0	Maximum value of the internal setpoint
C	PV_AH_Li	95.0	Upper alarm limit for the process value
C	PV_AH_En	1	Enable upper alarm limit
C	SettliFa	0.0	Transient recovery time factor to return to deadband
C	Feature.Bit30	1	Dynamic deactivation of deadband upon leaving deadband
C	PV_AH_Ac		Interconnection to the outlet valve (LIC_Buffer\to_Actor_Slave.BoStru3)
C	PhaseDeadband		Interconnection for deadband disabling upon feedforward control (DynDeadband\Deadband_disable.In)
IF_SFC	SP_Ext		Interconnection for operator setting of setpoint for comparison (Compare\SP_Level.PV_In)
IF_SFC	FFwd		Interconnection for disturbance dynamic deadband (DynDeadband\DV_to_MV.In)
to_Actor_Slave	BoStru3		Interconnection to PID controller (LIC_Buffer\C.PV_AH_Ac)
to_Actor_Slave	Out		Interconnection to the valve (YC_Outlet_Buffer\from_Ctrl.In)
from_Actor_Slave	In		Interconnection to the valve (YC_Outlet_Buffer\to_Ctrl.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_Buffer\PV_in_percent.Out)

**NOTE** Determined by the nature of the process, the level does not have to correspond exactly to the setpoint but must instead be in a mid-container zone instead. For this reason, it is a P-controller with a relatively small controller gain (<1) and an activated deadband. In order to avoid an oscillation around the deadband limit, the dynamic deadband disabling is effected via the feature bit 30 of the "PIDConL" function block. If the fill level leaves the deadband, this is deactivated and the fill level is brought to the center of the dead zone by the now active control. Only then is the control deactivated again and the manipulated variable is held.

**NOTE** Feedforward control is realized via the "PIDConL.FFwd" connection. The value of "FFwd" is internally added to the manipulated variable "MV" by the controller and thus directly affects the position of the actuator. The flow measurement of the container inlet is used as the disturbance variable.

### Dyn\_Deadband

Due to inflow fluctuations, feedforward control leads to a permanent actuator activity despite the active controller deadband. This undesirable behavior is suppressed in the "Dyn\_Deadband" CFC. In order to calculate the appropriate value for feedforward control, a characteristic curve for the effect of the disturbance variable on level control is stored.



1. Filtering of steep signal gradients (first order lag with 3 seconds time-constant)
2. Calculation of the upper limit for the adoption of a new disturbance value (Addition)
3. Calculation of the lower limit for the adoption of a new disturbance value (Subtraction)
4. Evaluation as to whether a limit has been exceeded or undercut
5. Deactivation of disturbance variable deadband upon disabling of controller deadband
6. Switchover between new and old disturbance variable
7. Conversion of disturbance variable to manipulated variable signal with the help of a polygon function block

**NOTE** In practice you will have to determine the interpolation values of the polygon function block either experimentally or based on pre-existing measurements. When the deadband is disabled, the associated outflow valve positions are recorded for the various values of the disturbance variable which lead to the desired constant level. The value pairs "disturbance variable measurement / valve position" yield the different interpolation points "InX / OutX" of the polygon module.

## YC\_Outlet\_Buffer

The instance has the following parameterization.

Block	Connection	Value	Use
V	MV		Interconnection to valve simulation (Sim_Buffer\PT1.In)
V	SafePos	1	Safety position is open status
V	Monitor	1	Display of readback signal in the OS
from_Ctrl	In		Interconnection to the controller (LIC_Buffer\to_Actor_Slave.Out)
from_Ctrl	BoStru3		Interconnection to the Interlock (YC_Outlet_Buffer\Intlock.In1)
to_Ctrl	Out		Interconnection to the controller (LIC_Buffer\to_Actor_Slave.In)
MV_Out	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)
Intlock	InvIn01	1	Inversion of Input 01
Intlock	Logic	OR	OR input interconnection

### NOTICE

#### Container overflow

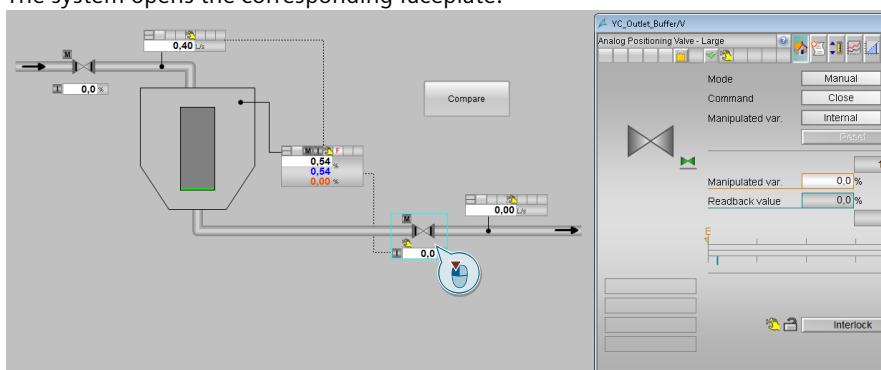
In the case of control with deadband, a safety logic must also be implemented in order to avoid overflow of the container at all costs. For this purpose, an interlock is implemented which forces the valve immediately into the safety position (in this case open) in the event of an overflow risk.

## Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

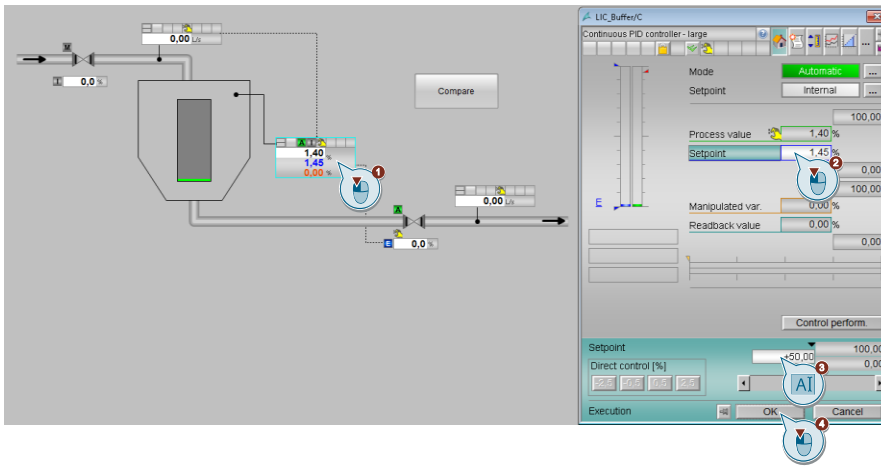
For commissioning, proceed as follows:

1. Click on the module symbol of the "YC\_Outlet\_Buffer" valve.  
The system opens the corresponding faceplate.

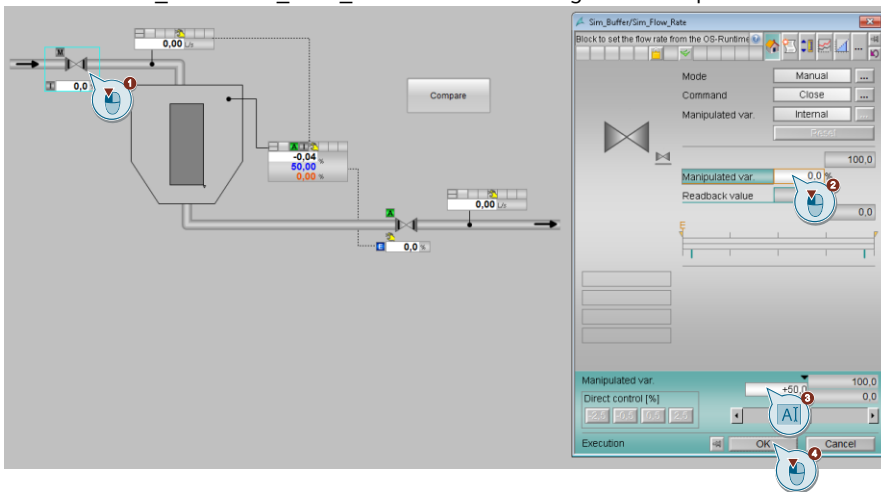


2. In the faceplate, change the operating mode to "Automatic".
3. Switch to controller "LIC\_Buffer" and change the operating mode of the controller to "Automatic".
4. Enter a setpoint of 50 %.





5. Switch to "Sim\_Buffer/Sim\_Flow\_Rate" valve and change the manipulated variable to 50 %



6. Wait for about 3 minutes and then enter a new setpoint of 25 % for the "Sim\_Buffer/Sim\_Flow\_Rate" valve.
7. Close the faceplate and observe the plotter for about two minutes until the setpoint has been reached again.
8. Then click on the "Start/Stop" icon on the toolbar of the OnlineTrendControl.

## Evaluation

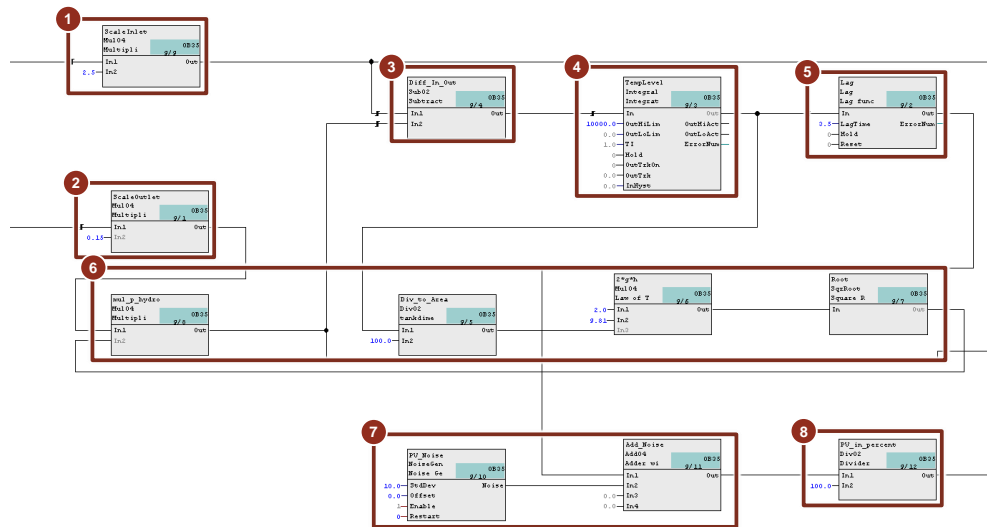


1. After the inflow has been reduced, the feedforward compensation reduces the setpoint of the outflow valve such that the tank level does not leave the deadband. In this case the controller does not need to intervene.
2. Thanks to the relatively wide deadband, the fill level does not reach the setpoint exactly again, but instead remains slightly below the setpoint. However, for this no further intervention of the controller via the outlet valve is necessary, so that the valve can be operated in a low-wear manner. Outflow keeps constant for longer time intervals.

## 5.1.3. Simulation - structure and parameterization

"Sim\_Buffer" and "Sim\_Level" simulations are of identical structure and are valid for the level controls in Sections 5.1.1 and 5.1.2. This means the results obtained from the diverse control concepts can be compared with each other.

Each simulation consists of three separate sheets: Part 1 contains the simulation of the level and calculates the flow rate of the outflow.



1. Calculation of the flow for the inlet (valve opened by 100 % corresponds to inflow of 250 l/s)
2. Calculation of the flow for the outlet (valve opened by 100 % corresponds to inflow of 0.48 m<sup>2</sup>)
3. Determination of level change (addition of inflow and subtraction of discharge)
4. Formation of an integral value by integrating the change in flow (every second)
5. Delay in level (PT1 response with 3.5-second delay)
6. Calculation of flow rate for discharge according to Torricelli's Law
7. Creation of measurement noise
8. Conversion of level into percentage

### NOTE

According to Torricelli's Law, the higher the level, the higher the flow speed in the container outflow, proportional to the square root of the fill level. As a consequence, for the same valve position the discharge rate will vary depending on the fill level of the container:

Torricelli's efflux velocity theorem:  $v \sim \sqrt{2 \cdot g \cdot h}$

$$q = A \cdot v$$

v: Efflux rate  
constant

h: Fill height

q: Outflow quantity

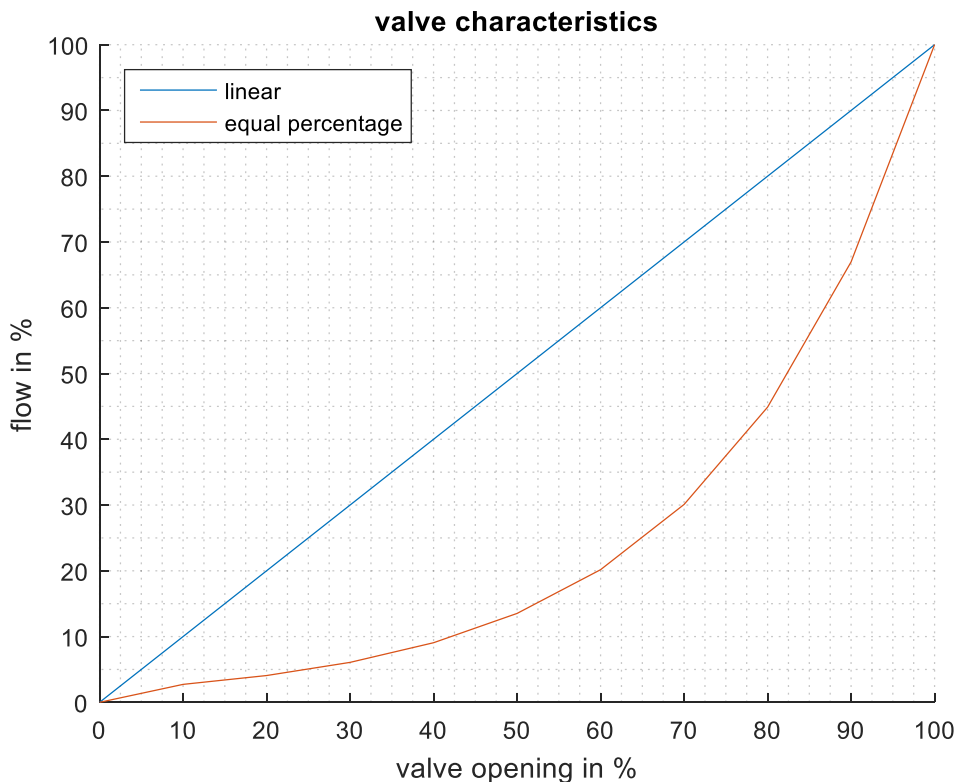
A: Efflux cross-section

g: Gravitational

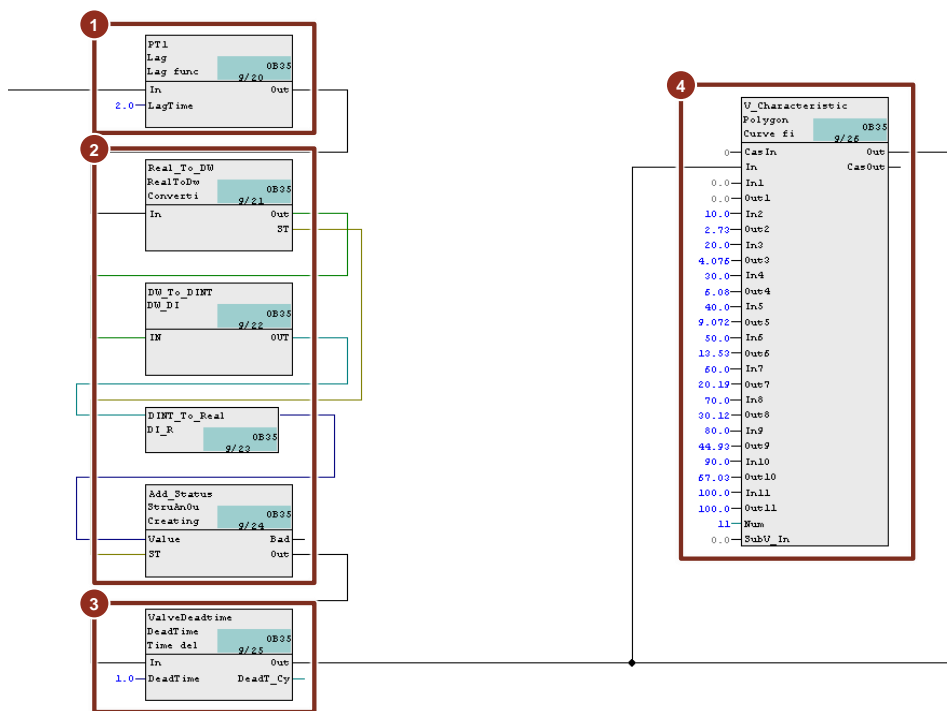
On sheet 2 an equal percentage characteristic line for the outlet valve is simulated.

In addition, the valve reaction is delayed with respect to the valve position setpoint, and the valve position is discretized to simulate the behavior of an electro-pneumatic valve positioner.

The following figure shows a linear and an equal-percentage valve characteristic line:



**NOTE** For further information about the equal-percentage valve characteristic line please refer to standard VDI-2173.



1. Delay in valve actuation (first order lag with time constant 2 seconds)
2. Valve actuation in integer numbers (1 % steps)
3. Dead time of valve actuation (delay of 1 second)
4. Approximation of the equal percentage valve characteristic by means of a polygon function block

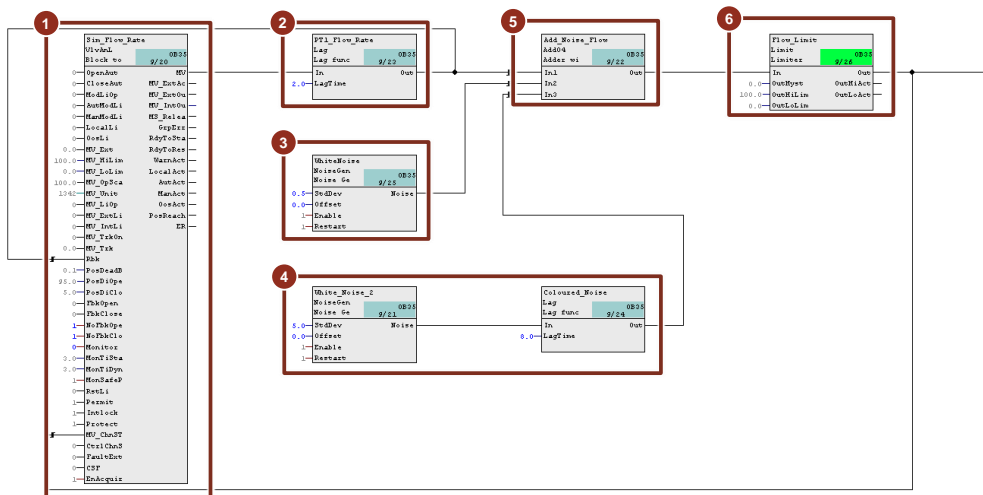
**NOTE** The tank outlet valve is further adapted to a realistic valve behavior through a small first order lag, a dead time and a discretization of the valve position to integer percentages.

This means that the valve position follows the manipulated variable of the master level controller with a certain sluggishness. The discretization only allows integer percentage values, i.e. the valve simulation cannot reach the setpoint position with infinite accuracy. The equal-percentage characteristic leads to a non-linearity in the actuator.

**NOTE** Both the tank simulation and the actuator have a non-linear behavior. Therefore, a non-linear characteristic curve must be inserted with the aid of a polygon function block between the disturbance variable measurement and the feedforward control.

The interpolation points of this characteristic curve can be determined experimentally. To do this, for different inflow rates the actuator must be adjusted until the container level stays constant at the desired value (container mid-height). The registered value pairs "Inflow measured/Valve position" can then be used for the polygon block.

On Sheet 3 of the CFC the inflow with disturbance and measurement noise is simulated.



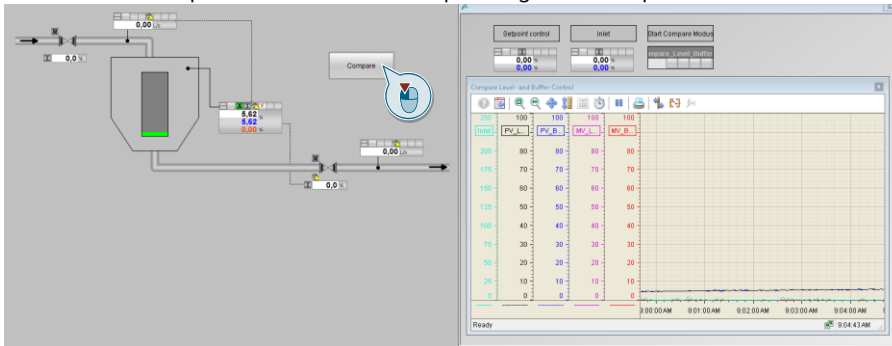
1. Technological valve operating module for inflow modification in the OS
2. Delay in inflow (first order lag with time constant 2 seconds)
3. Generation of measurement noise (white noise)
4. Generation of inflow disturbance (colored noise)
5. Determination of inflow quantity with disturbance and measurement noise (addition)
6. Limitation of inflow to 0 to 100 %

## 5.1.4. Comparison of exact level control with buffer control including feedforward disturbance compensation

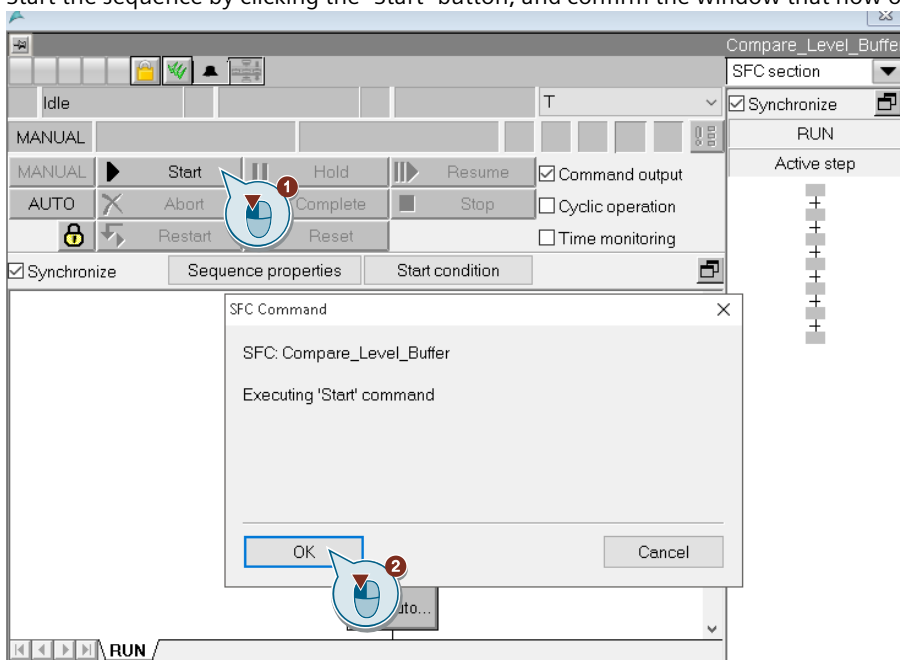
The two concepts presented for level control are compared against each other in this chapter. In order to be able to compare the two simulations both must have the same setpoints and disturbance values. A comparison mode has been implemented to enable these requirements to be fulfilled. This mode allows to simultaneously modify inflows and setpoints for both simulations.

To start the comparison, proceed according to the following instructions:

1. Open the plant overview picture "Level Control" or "Buffer Control".
2. Click on the "Compare" button. The corresponding window opens.



3. Click on the SFC icon "Compare\_Level\_Buffer". The corresponding window opens.
4. Start the sequence by clicking the "Start" button, and confirm the window that now opens by "OK".

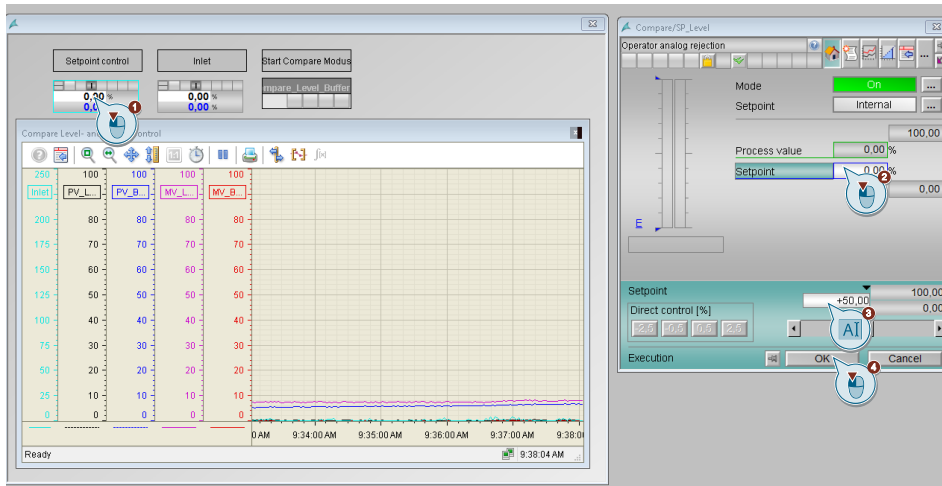


Wait for about 10 seconds until the SFC has run.

### NOTE

Now all the valves and controllers are pre-configured in such a manner that manipulated variable and setpoint can be defined via the two analog input windows in the "Compare" window.

5. Switch to analog input window "SP\_Level" and enter a setpoint of 50 %.



6. Switch to analog input window "MV\_InletValve" and enter a setpoint of 50 %.
7. Wait for about 3 minutes and enter a new inflow of 75 % in the "MV\_InletValve" analog window.
8. Wait 2 more minutes and enter a new inflow of 25 % in the "MV\_InletValve" analog window.
9. Wait 3 more minutes and enter a new inflow of 50 % in the "MV\_InletValve" analog window.
10. Close the faceplate and observe the plotter for about two minutes until the setpoint has been reached.
11. Then click on the "Start/Stop" icon on the toolbar of the OnlineTrendControl.

## Evaluation



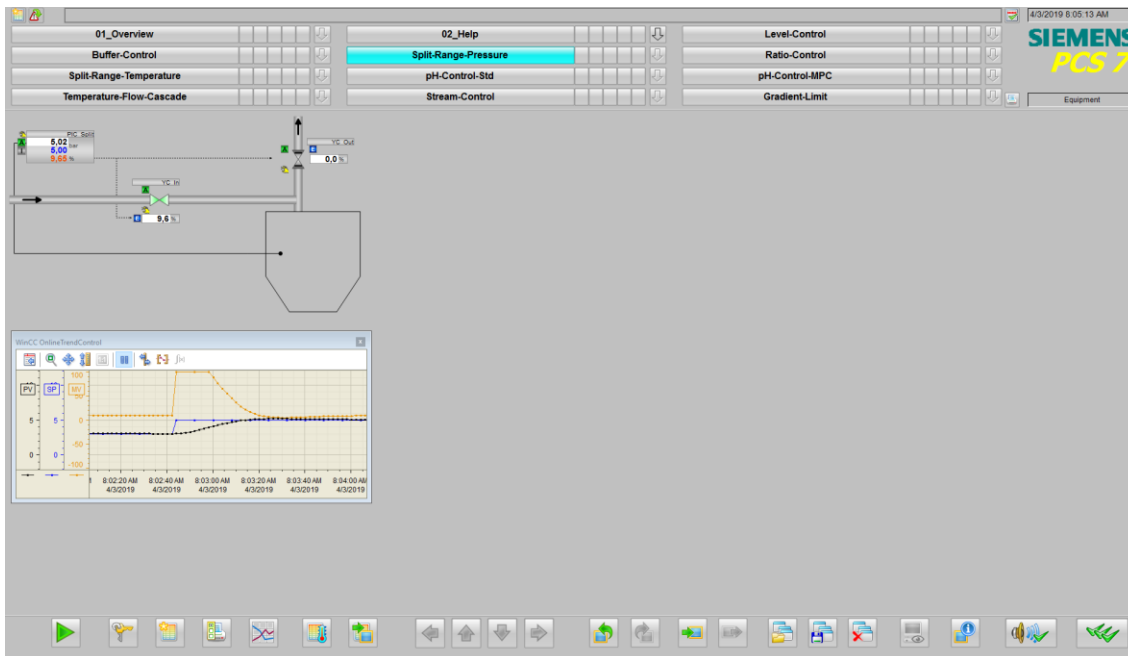
1. After the inflow increase, the level rises above the setpoint for both control concepts. The PI controller for the exact level control detects the change in level and consequently increases the manipulated variable of the outlet valve until the filling level has reached the desired setpoint again. Control towards the setpoint, however, produces permanent fluctuations of the manipulated variable for the outlet valve. In the case of the buffer level control with feedforward disturbance compensation, the changed inflow is detected as a change in the disturbance variable and the manipulated variable is then moved accordingly. The immediate reaction to the inflow change provides a faster intervention and the level rises less compared to PI control. Thanks to the relatively wide deadband, the level does not leave the setpoint area and the controller has to re-adjust less frequently, which eases the wear of the actuation mechanism.
2. With the inflow change from 75 % to 25 % of the maximum inflow, both fill levels sink and the fill level of the buffer leaves the deadband. This activates the P controller and the deadband is temporarily deactivated. As soon as the level approaches the setpoint again, the deadband is activated and the manipulated variable remains constant. In a manner analogous to the inflow change described in point 1, the PI controller reacts to the exact filling level with a change of the outflow valve until the fill level has reached the setpoint.
3. The third inflow change occurs before the PI controller has reached the fill level setpoint, the latter thus reacts by overshooting the fill level more than with the inflow change under point 1. In contrast to this, the buffer level controller is again within the setpoint range and therefore reacts only to a change of the inflow with a change of the manipulated variable via the feedforward control.



# 5.2. "Split-Range-Pressure" control

Pressure control in pipelines is similar to flow control and typically allows fast control loops. For pressure control in tanks, time-constants depend on the ratio of tank volume to maximal inflow and outflow. The tank pressure is increased by feeding an inert gas (e.g. nitrogen) via a supply line. Opening the purge valve allows the gas mixture to escape and the container pressure is reduced. The controller responds to pressure changes and compensates them by opening the supply line or the outlet valve.

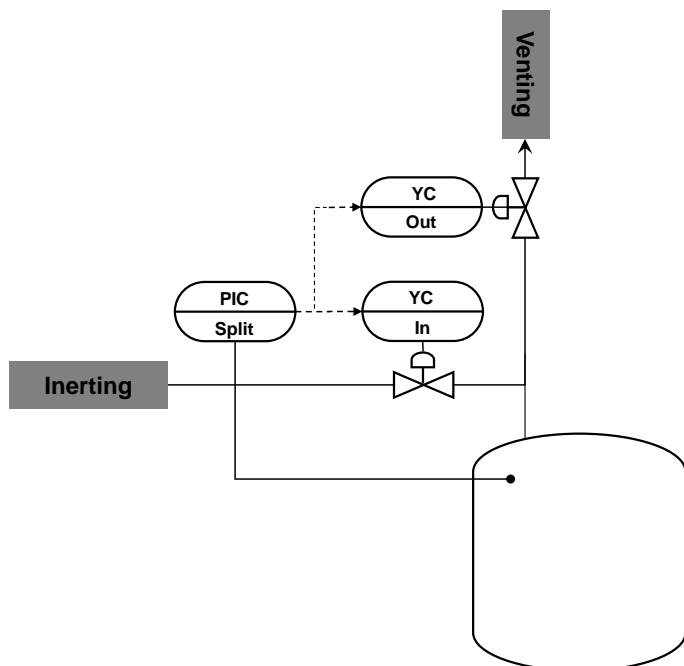
In the following example, control of the container pressure is solved by pressure supply and purge valve.



## Overview

### P&I Diagram

The P&ID below symbolically represents all of the components, such as field devices and tanks relevant to operation.



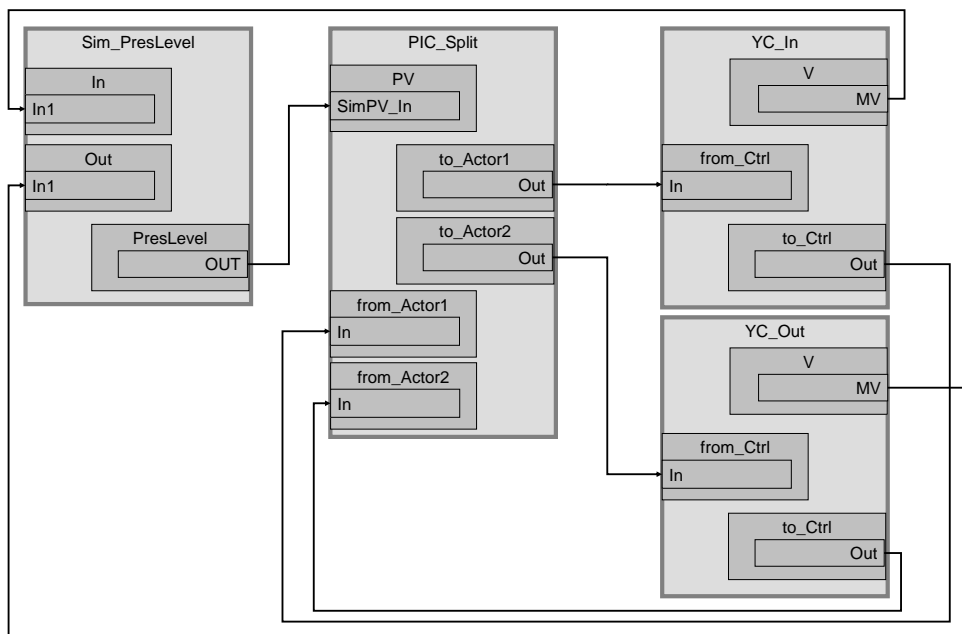
### CM and variants

The "Split-range pressure" equipment module consists of three connected CMs and one simulation chart. In the simulation chart, a container pressure and the effects due to feeding and venting inert gas are simulated.

The following table provides an overview of the CMs of the equipment module including the associated CMTs.

CM	CMT	Selected variants	Description
PIC_Split	"PIDConSplitRange"	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale#</li> </ul>	Pressure control with one manipulated variable and two actuators
YC_In	"ValAn"	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve for supplying inert substances
YC_Out	"ValAn"	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve for ventilation

In the figure below, the structure with the cross-chart interconnections is shown in simplified form.



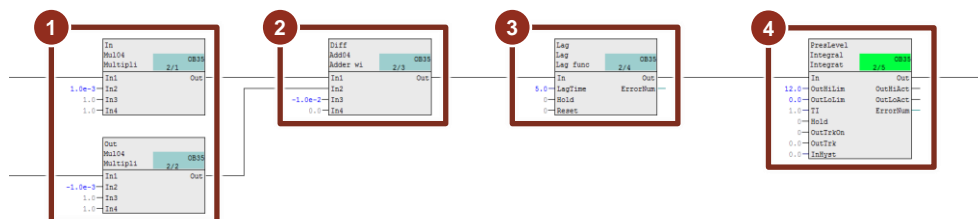
"PIC\_Split" acquires the container pressure ("Sim\_PresLevel" simulation chart) and regulates it with the help of the two control valves "YC\_In" and "YC\_Out".

**Structure and parameterization**

**"Sim\_PresLevel" simulation**

The pressure change in the container due to inerting or venting is simulated in the "Sim\_PresLevel" CFC.

The figure below shows the sequence of the simulation.



1. Calculation of the pressure change starting from the proportionality factor (valve opened by 100 % corresponds to a change in pressure of 0.1 bar)
2. Reduction in the pressure by 0.01 bar, e.g. due to container pressure loss
3. Time lag of the change in pressure
4. Time integral of pressure changes (every second)

**PIC\_Split**

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	10.0	Scaling of the process value upper limit
PV_Unit	In	1137	Process value unit in bar
C	NegGain.Value	1	Reversal of the response characteristic for the valve (valve 1 opens in the case of a negative control difference instead of a positive one)
C	Gain.Value	8.0	Controller gain
C	TI.Value	75.0	Controller lag
C	SP_InHiLim	10.0	Maximum value of the internal setpoint
C	ManLoLim (hidden)	-100.0	Lower limit for the manipulated variable in manual mode
Split range	InScale.High	100.0	Marginal range for the input signal
Split range	InScale.Low	-100.0	
Split range	NeutPos	0.0	Neutral position
to_Actor1	Out		Interconnection to the valve (YC_In\from_Ctrl.In)
to_Actor2	Out		Interconnection to the valve (YC_Out\from_Ctrl.In)
from_Actor1	In		Interconnection to the valve (YC_In\to_Ctrl.Out)
from_Actor2	In		Interconnection to the valve (YC_Out\to_Ctrl.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_PresLevel\PresLevel.Out)

**NOTE**

The program "PID Tuner" is available for commissioning the "PIC\_Split" controller. At the beginning, data recording for the "PID-Tuner" is done in an operating range where only positive values of the manipulated variables are expected. After this, a comparable experiment is made in an operating range where only negative manipulated variables occur.

If both part transfer functions for venting and inerting show significantly different values for process gain, this must be compensated by a different gradient of both branches of the split range characteristic curve.

Further information and configuration guidelines can be found in the Online Help for the "SplitrangeControl" process tag type.

## YC\_In and YC\_Out

The instances have the following parameterization.

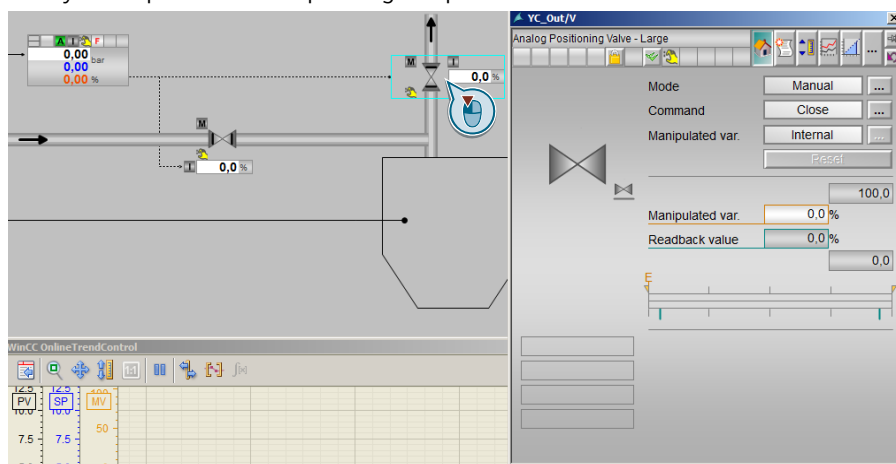
Block	Connection	Value	Use
V (YC_In) (YC_Out)	MV		Interconnection for the simulation (Sim_PresLevel\In.In1) (Sim_PresLevel\Out.In1)
from_Ctrl (YC_In) (YC_Out)	In		Interconnection to the controller (PIC_Split\to_Actor1.Out) (PIC_Split\to_Actor2.Out)
to_Ctrl (YC_In) (YC_Out)	Out		Interconnection to the controller (PIC_Split\from_Actor1.In) (PIC_Split\from_Actor2.In)
MV_Out (YC_In) (YC_Out)	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)

## Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

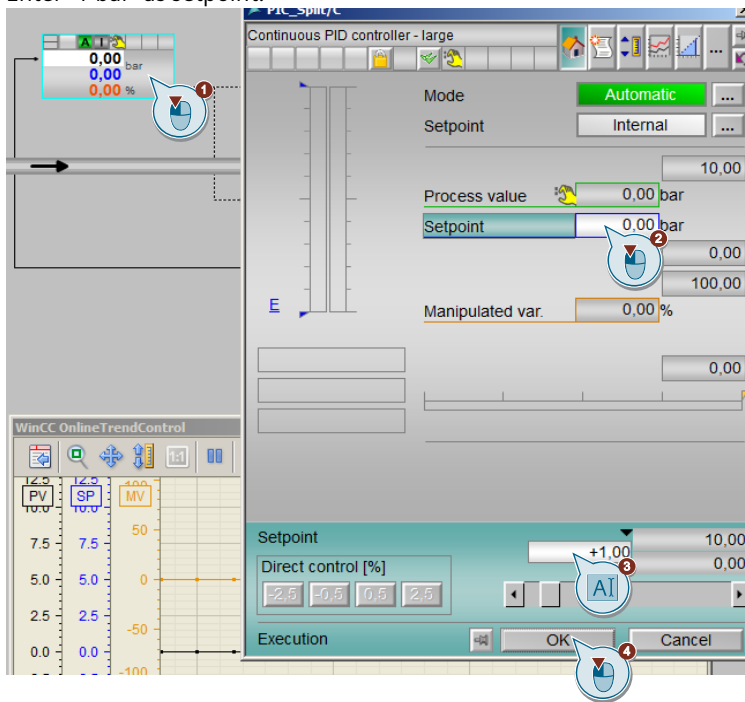
Proceed as follows:

1. Click on the symbol display of valve "YC\_Out".  
The system opens the corresponding faceplate.



2. In the faceplate, change the operating mode to "Automatic".
3. Switch to valve "YC\_In" and change the operating mode to "Automatic".
4. Switch to controller "PIC\_Split" and change the operating mode of the controller to "Automatic".

5. Enter "1 bar" as setpoint.

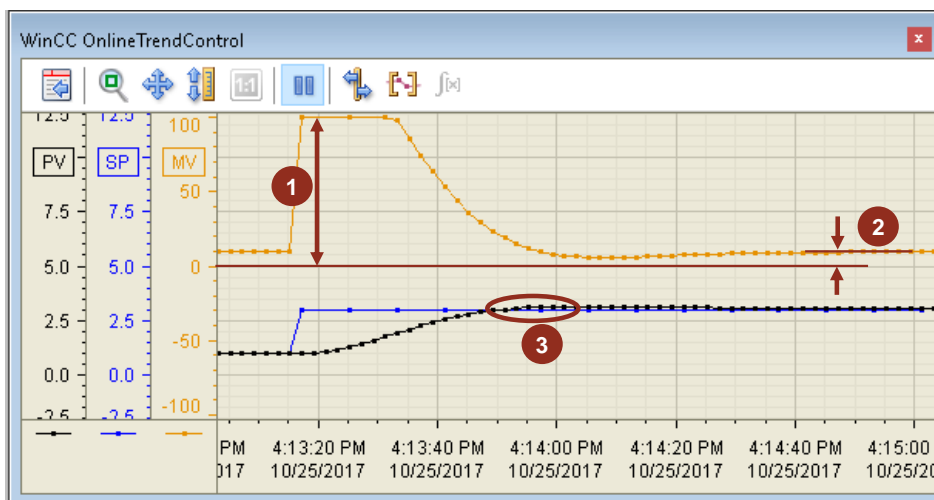


The new setpoint will have been reached after about two minutes. To compensate the pressure loss of the container, the valve is opened to about 10 % for venting.

6. Specify "3 bar" as new setpoint for the controller.

7. Close the faceplate and observe the plotter for about two minutes until the new setpoint has been reached.

### Evaluation



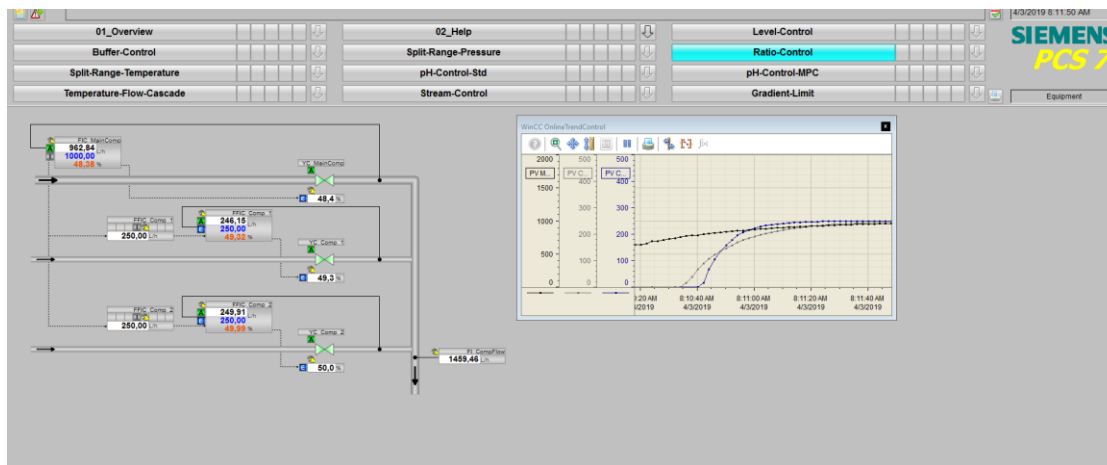
1. After the setpoint step, the manipulated variable is set to -100 and by this, the pressure feed valve is opened.
2. The process value slightly exceeds the setpoint; the pressure feed valve is closed evenly.
3. After reaching the setpoint, the pressure feed valve has been opened by about 10 %; this means that the pressure loss of the container has been compensated.

# 5.3. "Ratio-Control"

In case of ratio control, different gases or other input materials are fed in fixed mixing ratios into a tank via inlet lines.

The ratio control scheme consists of one controller for the main input material (master controller) and one controller for each additional input material (slave controller).

The example below describes feed control with two input materials, and later on is expanded with another input material.

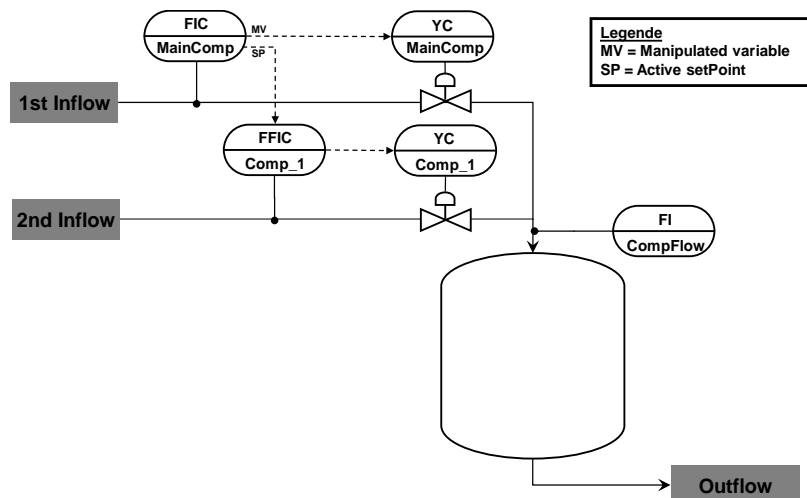


## Overview

Below, the structure in the P&ID is shown and all of the CMs and the simulation of the equipment module are described.

## P&I Diagram

The P&ID below symbolically represents all of the components, such as field devices and containers relevant to operation.



## CM and variants

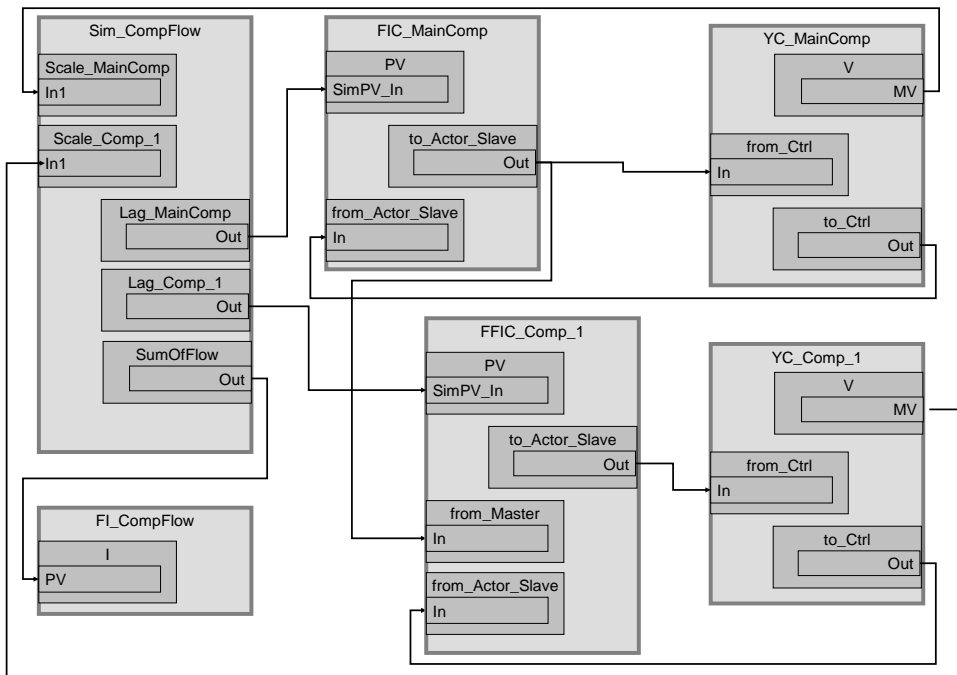
The "ratio control" equipment module consists of four connected CMs and one simulation chart. On the simulation chart, the system calculates the total of all the inflows (input materials) and displays them.

The following table provides an overview of the CMs of the equipment module including the associated CMTs.

CM	CMT	Selected variants	Description
FIC_MainComp	"Ctrl"	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale#</li> </ul>	Flow control of the main input material
FFIC_Comp_1	"PIDConRatio"	<ul style="list-style-type: none"> <li>IF_Master#</li> <li>PV</li> <li>PV_Scale#</li> </ul>	Flow control of the additional input material
YC_MainComp	"ValAn"	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> </ul>	Control valve for the main input material

CM	CMT	Selected variants	Description
		<ul style="list-style-type: none"> <li>RbkReturn</li> <li>YC</li> </ul>	
YC_Comp_1	"ValAn"	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve for the additional input material
FI_CompFlow	"MonAn"	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale#</li> </ul>	Display of the calculated overall inflow

In the figure below, the structure with the cross-chart interconnections is shown in simplified form.



Control "FIC\_MainComp" acquires the flow of the main input material and regulates it using control valve "YC\_MainComp". In addition, "FIC\_MainComp" transfers its own setpoint to process tag "FFIC\_Comp\_1". This means that "FIC\_MainComp" is the master controller for "FFIC\_Comp\_1".

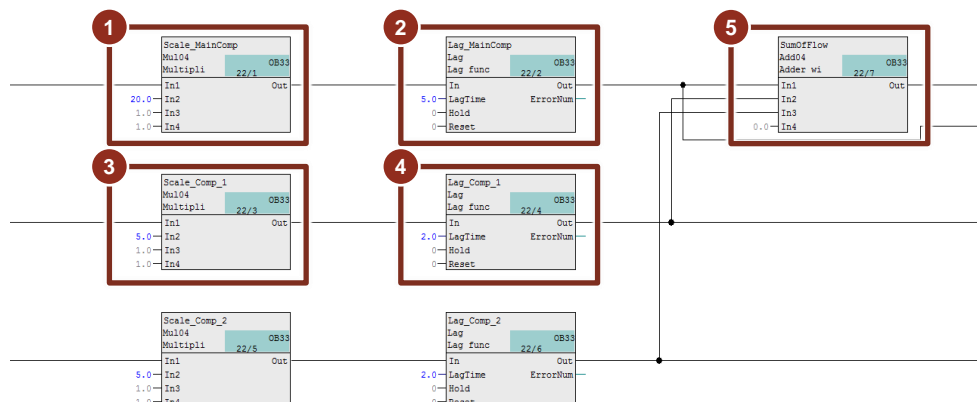
Control "FFIC\_Comp\_1" acquires the flow of the additional input material and regulates it using control valve "YC\_Comp\_1". "FFIC\_Comp\_1" receives the setpoint from control "FIC\_MainComp"; this means that "FFIC\_Comp\_1" is the slave controller.

## Structure and parameterization

### "Sim\_CompFlow" simulation

The flow of the main input material and the additional input material are simulated in the "Sim\_CompFlow" CFC and the overall flow rate is calculated too. Apart from this, the system displays the flow rate based on process tag type "MonAn".

The figure below shows the sequence of the simulation.



1. Calculation of the flow for the main input material (valve opened by 100 % corresponds to inflow of 2000 l/h)
2. Delay in change of flow (PT1 response with 5-second delay)
3. Calculation of the flow for the main input material (valve opened by 100 % corresponds to inflow of 500 l/h)
4. Delay in change of flow (PT1 response with 2-second delay)
5. Determination of the complete flow quantity (addition)

Inputs "In1" of highlighted blocks 1 and 3 get their manipulated variables from valve blocks "I" of process tags "YC\_MainComp" and "YC\_Comp\_1". The "Out" outputs of highlighted blocks 2 and 4 are interconnected with the channel blocks of the controls.

### FIC\_MainComp

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	2000.0	Scaling of the process value upper limit
PV_Unit	In	1353	Unit of the process value l/h (liters per hour)
C	Gain.Value	0.05	Controller gain
C	Tl.Value	2.2	Controller lag
C	SP_InHiLim	2000.0	Maximum value of the internal setpoint
to_Actor_Slave	Out		Interconnection to the valve and slave controller (YC_MainComp)from_Ctrl.In) (FFIC_Comp_1)from_Master.In)
from_Actor_Slave	In		Interconnection to the valve (YC_MainComp)to_Ctrl.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\\Activate_Simulation\\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_CompFlow\\Lag_MainComp.Out)

#### NOTE

In the current configuration, the master controller can carry out control regardless of the status of the slave controller. If you do not want this behavior, you can, for example, interconnect the "CascaCut" output of the slave controller to the "Interlock" input or block (can be selected optionally). If you want to use other signals of the slave controller such as "LockAct" (locking active) or "OosAct" (out of service) for locking, you can add another "ComStruOut" communication block to the slave controller and interconnect block outputs BoStru1 thru BoStru3 to the locking block.



**NOTE**

The setpoint is transferred to the controller process tag(s) of the additional input material(s). Using the setpoint instead of the manipulated variable means that the controller structure **does not** correspond to a typical cascade controller.

The "PID Tuner" program is available for commissioning the controller. If there is a considerably difference in closed loop response time after the optimization, you can try adapting and compensating the parameters of both control loops manually. The highest priority however is the stability of the transient response of both individual control loops. In this context, there can be a temporary deviation from the specified ratio in the case of setpoint steps. If such temporary deviations in one direction must not occur at all due to safety reasons, additional logic has to be implemented. E.g. burner control with flow controllers for fuel gas and air in a fixed ratio: in this case you have to make sure that there is always a little bit more air than required, because a deficiency of air can be dangerous even in short time intervals.

**FFIC\_Comp\_1**

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	500.0	Scaling of the process value upper limit
PV_Unit	In	1353	Unit of the process value l/h (liters per hour)
C	Gain.Value	0.25	Controller gain
C	TI.Value	4.1	Controller lag
C	SP_InHiLim	500.0	Maximum value of the internal setpoint
to_Actor_Slave	Out		Interconnection to the valve (YC_Comp_1\from_Ctrl.In)
from_Actor_Slave	In		Interconnection to the valve (YC_Comp_1\to_Ctrl.Out)
from_Master	In		Interconnection to the master controller (FIC_MainComp\to_Actor_Slave.Out)
Ratio	RatHiLim	1	Upper limit (ratio)
Ratio	RatLoLim	0	Lower limit (ratio)
Ratio	RatLiOp	0	Ratio specification by user
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_CompFlow\Lag_Comp_1.Out)

**YC\_MainComp and YC\_Comp\_1**

The instances have the following parameterization.

Block	Connection	Value	Use
V (YC_MainComp) (YC_Comp_1)	MV		Interconnection for the simulation (Sim_CompFlow\In.In1) (Sim_CompFlow\Out.In1)
from_Ctrl (YC_MainComp) (YC_Comp_1)	In		Interconnection to the controller (FIC_MainComp\to_Actor_Slave.Out) (FFIC_Comp_1\to_Actor_Slave.Out)

Block	Connection	Value	Use
to_Ctrl (YC_MainComp) (YC_Comp_1)	Out		Interconnection to the controller (FIC_MainComp\to_Actor_Slave.In) (FFIC_Comp_1\to_Actor_Slave.In)
MV_Out (YC_MainComp) (YC_Comp_1)	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)

### FI\_CompFlow

The instance has the following parameterization.

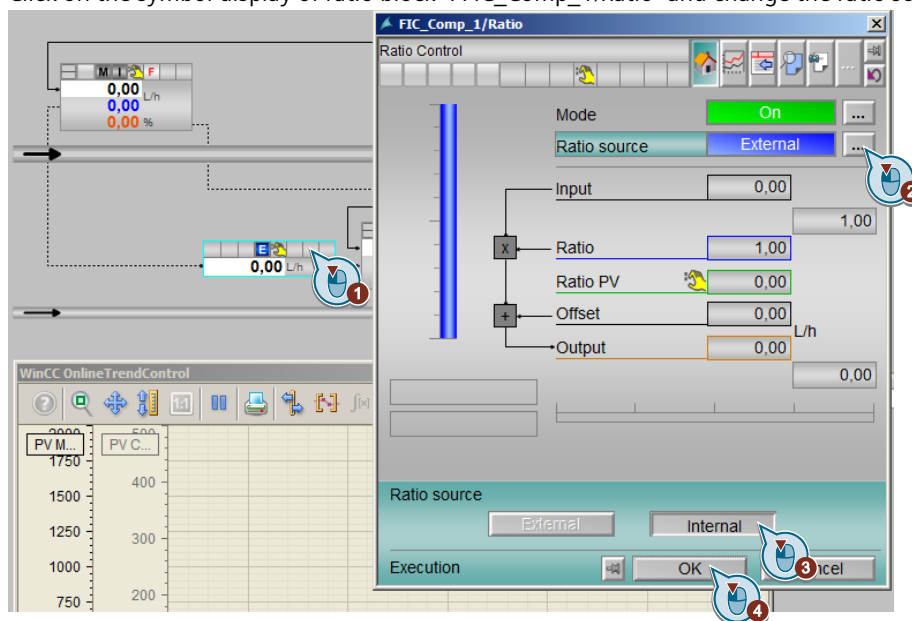
Block	Connection	Value	Use
PV_Scale	HiScale	3000.0	Scaling of the process value upper limit
PV_Unit	In	1353	Unit of the process value l/h (liters per hour)
I	PV		Interconnection for the simulation: (Sim_CompFlow/SumOfFlow.Out)

### Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

Proceed as follows:

1. Click on the symbol display of ratio block "FFIC\_Comp\_1/Ratio" and change the ratio source to "Internal".



2. Enter the new ratio of "0.25".  
The ratio corresponds to the factor of the flow setpoint at which the additional input material has to flow to the main input material.
3. Switch to valve "YC\_Comp\_1" and change the operating mode to "Automatic".
4. Switch to slave controller "FFIC\_Comp\_1" and change the operating mode to "Automatic" and the setpoint specification to "External".

#### NOTE

While master controller "FIC\_MainComp" is not working in automatic mode, it does not return a setpoint (proportionally) to the slave controller either.

5. Switch to valve "YC\_MainComp" and change the operating mode to "Automatic".

6. Switch to master controller "FIC\_MainComp" and change the operating mode to "Automatic".
7. Enter the setpoint "1000 l/h" in the master controller.

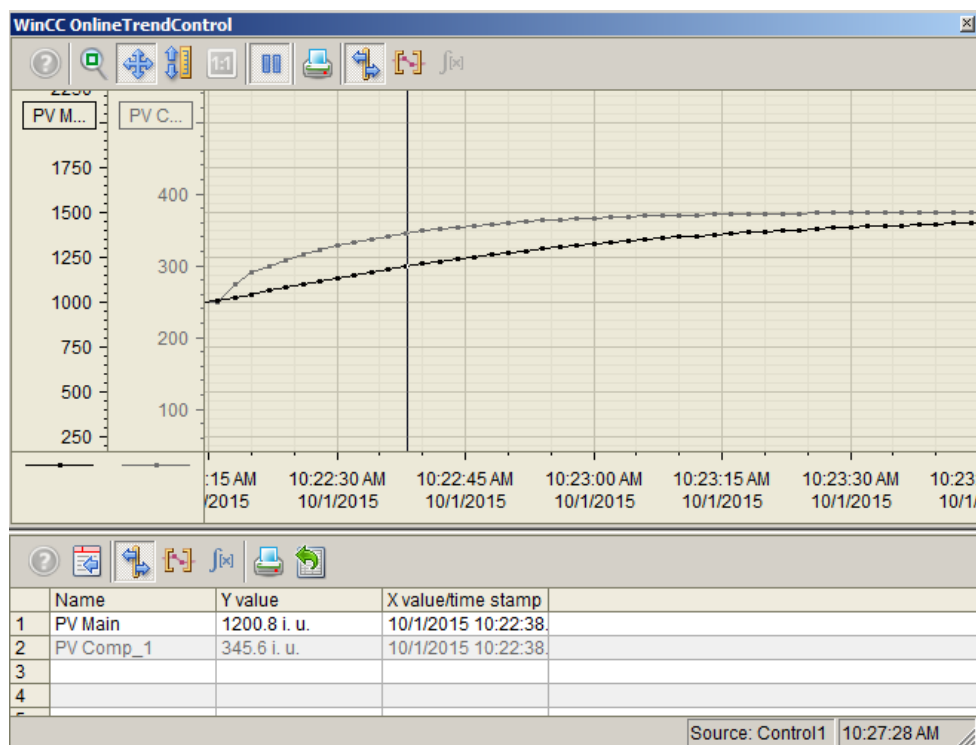
**NOTE** The system displays the current actual value of the ratio in the "Ratio" block, which results from the setpoint directed to the slave controller.

Both controller setpoints will have been reached after about 1 minute.

8. Enter a new setpoint of "1500 l/h" in master controller "FIC\_MainComp".
9. Wait for about 90 seconds and then click on the "Start/Stop" icon on the toolbar of the OnlineTrendControl.
10. On the toolbar of the OnlineTrendControl, click on the "Ruler" icon and move the ruler to the lowest value with the greatest deviation, as show in the evaluation below.

## Evaluation

The "OnlineTrendControl" that is embedded in the process picture is set to the maximum value ranges. If the ratio changes, the value range of the additional input material adapts automatically.



Due to the different response times of the controllers, the ratio is temporarily 29 % (0.29). Compared to the ratio setpoint of 25 % (0.25), a deviation of 4 % results temporarily before the correct ratio is reached in the steady state.

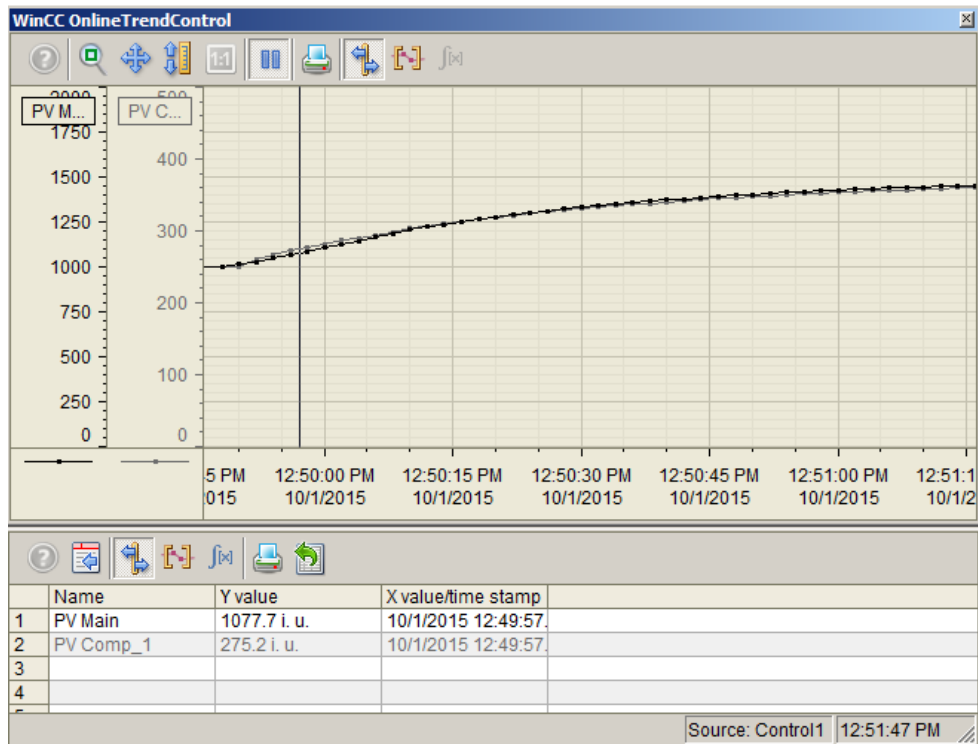
In this case, it is not possible to improve the controller design for slave controller "FFIC\_Comp\_1" by means of PID controller optimization, since the aim of the controller design is optimum tracking of the additional input material.

**NOTE** For further information and configuration guidelines, refer to the Online Help for the "RatioControl" process tag type. You can find the process tag type in "PCS 7 – Advanced Process Library".

The response curves from the OnlineTrendControl lead to the considerations below for the controller design to match the transient responses of the master and slave loops as closely as possible to one another:

- The relatively large deviation at the start of step response indicates that the gain of the slave controller is too high, i.e. the slave controller process value rises faster than the actual value of the master controller.
- The relatively slow speed with which the final value of the setpoint step-change is reached, indicates an integration time of the master controller that is too high, i.e. the master controller enters the steady state slower than the slave controller.

A change in the gain of slave controller "FFIC\_Comp\_1" from 0.25 to 0.1 with a simultaneous change in the integral-action time of master controller "FIC\_MainComp" from 2.2 to 2 generates the result below with the same setpoint steps.



Due to the different response times of the controllers, the ratio after optimization is temporarily 25.6 % (0.256). Compared to the set ratio of 25 % (0.25), a deviation of 0.6 % results briefly.

### Adding another input material

Using the "Ratio Control" equipment module, you can set up a large number of ratio controllers. The number of additional input materials is limited by the interlock block or the number of interlock inputs that it has.

#### NOTE

If the number of locking signals of the slave controller has to be acquired in the master controller, the options below are available for adapting the Ctrl type (CMT):

Group the signals of the communication blocks (from\_Actor\_Slave) using OR blocks. As a result, one valve and seven additional input materials are interconnected by means of one interlock block.

#### Disadvantage:

Inaccurate error display, i.e. the system does not differentiate between errors in the cascade controller, an "out of service" signal of the controller block, and a "Bad" status of the controller channel blocks.

Duplicate the existing interlock block and group the two (Out) outputs of the interlock blocks using an OR block. For interconnection (Out output) of the OR block, use the (Out output) interconnections of the existing interlock block.

You can call up the faceplate of the first interlock block from the controller's faceplate. The faceplate of the second interlock block is opened by means of its block display symbol in the process picture.

Replace the existing locking block with 8 input signals (Intlk08) with a locking block with 16 input signals (Intlk16). Apply all the interconnections of the previous locking block.

### Requirements

If different additional input materials are measured in different measurement units, the conversion factor in the ratio block also includes conversion of the units.

**NOTE**

In the case of different physical units, you must specify the other measurement unit for the additional input material. The ratio factor in the ratio function block now has to include the conversion from the flow unit of the master controller to the flow unit of the slave controller.

Additionally, when displaying the trend curves in a common diagram, it is advisable to label clearly.

If different travel ranges are needed in the case of the partial control loops of a ratio controller, you must delete the corresponding interconnections and parameterize them for the respective partial control loop.

**Description**

To add another additional input material to the equipment module, proceed as follows:

1. Copy CMs "FFIC\_Comp\_1" and "YC\_Comp\_1" at the same time. Paste the copied CMs back into the same hierarchy folder. Rename the process tags appropriately (below, the CMs will be referred to as "FFIC\_Comp\_2" and "YC\_Comp\_2").

**NOTE**

When you copy the process tags at the same time (highlight the process tags and then click on Edit > Copy on the menu bar), the connections between the highlighted process tags are retained.

2. Open process tag "FFIC\_Comp\_2" and make the following interconnections:

Block	Connection	Use
from_Master	In	Interconnection to the master controller (FIC_MainComp\to_Actor_Slave.Out)

3. The simulation model is designed for two additional input materials. Make the interconnections below in CFC "FFIC\_Comp\_2" to connect the second additional input material to the simulation.

Block	Connection	Use
PV	SimOn	Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)
PV	SimPV_In	Interconnection for the simulated process value (Sim_CompFlow\Lag_Comp_1.Out)

4. Open process tag "YC\_Comp\_2" and make the following interconnections in chart partition "A" sheet 1:

Block	Connection	Use
V	MV	Interconnection for the simulation (Sim_Level\Scale.In1)
MV_Out	SimOn	Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)

**NOTE**

When additional input materials are added to the "Ratio-Control" equipment module, you must compile and load the blocks and charts and compile the OS.

## 5.4. "Split-Range-Temperature" control

Temperature control in tanks, heat exchangers, columns or reactors typically involves large heat capacities and results in slow control loops. To achieve a specified temperature inside a tank, the system feeds either hot steam or cooling water via supply lines with control valves into the service medium side of a heat exchanger or reactor jacket. The reactor jacket can contain the service medium in the sense of a heat exchanger. On the other hand, there are external heat exchangers for reactors, where the reactor content is pumped through pipes to the heat exchanger and back. Due to separation by means of heat-permeable walls, all of these procedures are indirect heat transfers.

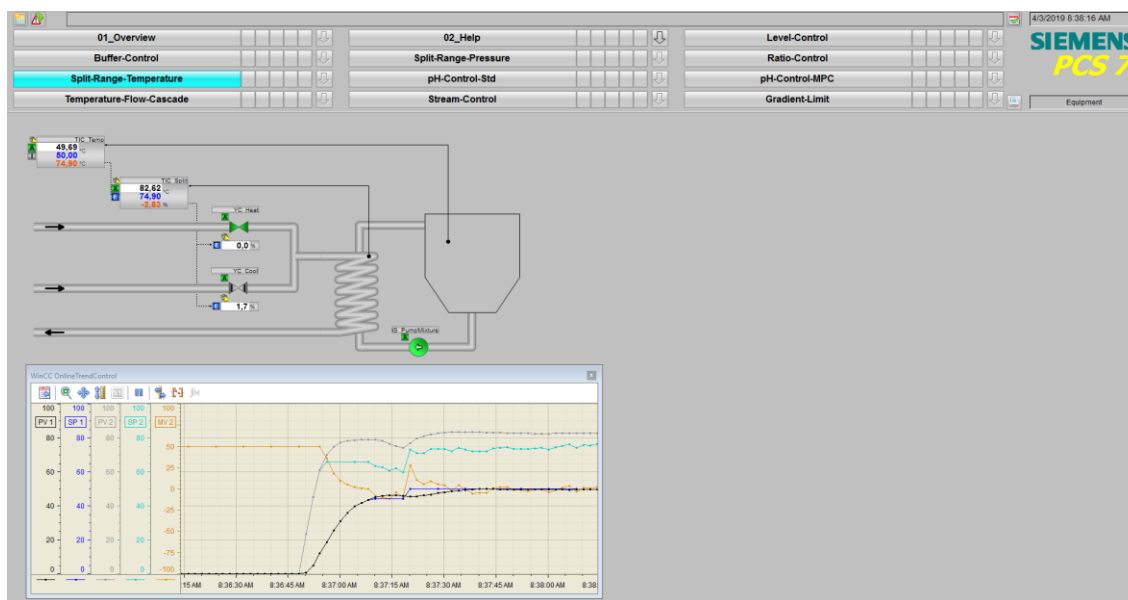
The usual assumption for temperature control of tanks is a complete mixture of tank content (e.g. via stirrer), such that it is sufficient to measure temperature at one single point and assume that this temperature is representative for the whole tank. Continuous turnover via pump provides homogenous temperature distribution in cooling jackets as well.

On the other hand, in heat exchangers that are not directly linked to a tank or reactor, typically only the outlet temperature of the product medium is measured and controlled. Inside the heat exchanger there are significant temperature gradients.

### NOTE

The "Split-Range-Temperature" equipment module can be used for tanks or reactors in which temperature control is provided via the reactor jacket or an external heat exchanger.

In the following example, reactor temperature control is carried out using an external heat exchanger.

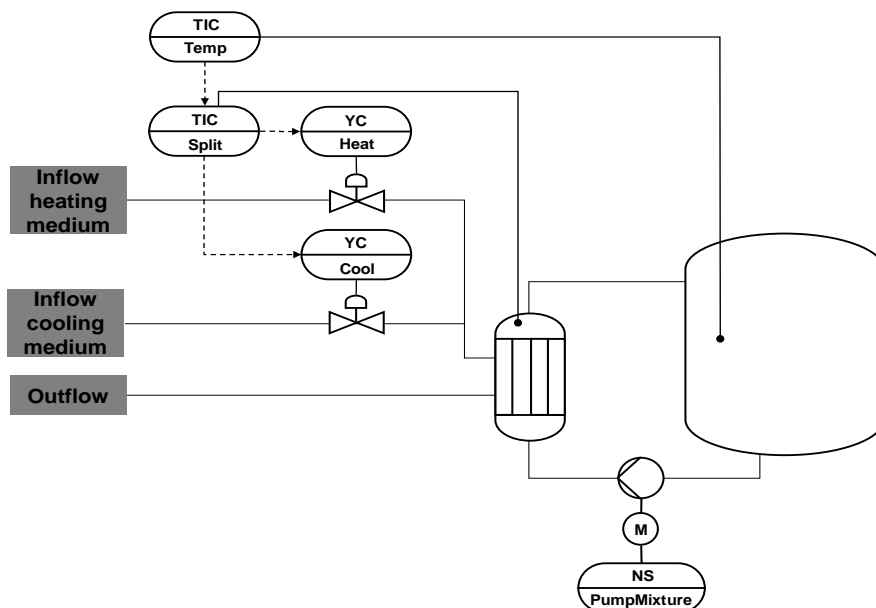


## Overview

Below, the structure in the P&ID is shown and all of the CMs and the simulation of the equipment module are described.

## P&I Diagram

The P&ID below symbolically represents all of the components, such as field devices and tanks relevant to operation.



## CM and variants

The "Split-range temperature" equipment module consists of four interconnected CMs, one CM for pump control, and one simulation chart. The simulation chart simulates the internal temperature of a container (input material mixture), the temperature of a heat exchanger, and the effect of changes in temperature (heating steam and cooling water).

The following table provides an overview of the CMs of the equipment module including the associated CMTs.

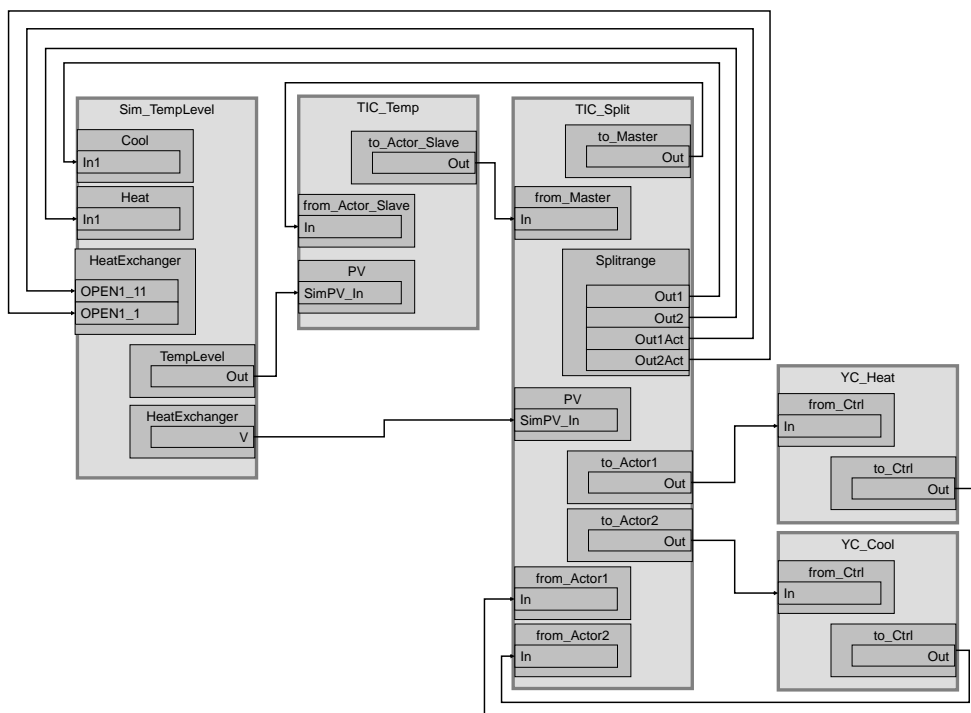
CM	CMT	Selected variants	Description
TIC_Temp	Ctrl	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale#</li> </ul>	Master controller for temperature control
TIC_Split	PIDConSplit Range	<ul style="list-style-type: none"> <li>IF_Master#</li> <li>PV</li> <li>PV_Scale#</li> </ul>	Slave controller for split-range control with one manipulated variable and two actuators
YC_Heat	ValAn	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve for the first manipulated variable
YC_Cool	ValAn	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve for the second manipulated variable
NS_PumpMixture	Mot	<ul style="list-style-type: none"> <li>1Fbk#</li> </ul>	A pump (e.g. a flow pump) for continuous pumped circulation of the contents of the container

### NOTE

The "NS\_PumpMixture" CM is interconnected in the SFC (Sequential Function Chart) It is not necessary to interconnect with other process tags in the "Split-Range Temperature" equipment module.

To ensure that the system does not generate an error message due to a missing feedback signal, the "Start" output signal is interconnected with the "FbkRun" input signal of motor block "U".

In the figure below, the structure with the cross-chart interconnections is shown in simplified form.



Controller "TIC\_Temp" uses the simulated internal container temperature from simulation chart "Sim\_TempLevel" and generates the setpoint specification for the split range control. The desired temperature progression is thus configured in process tag "TIC\_Temp".

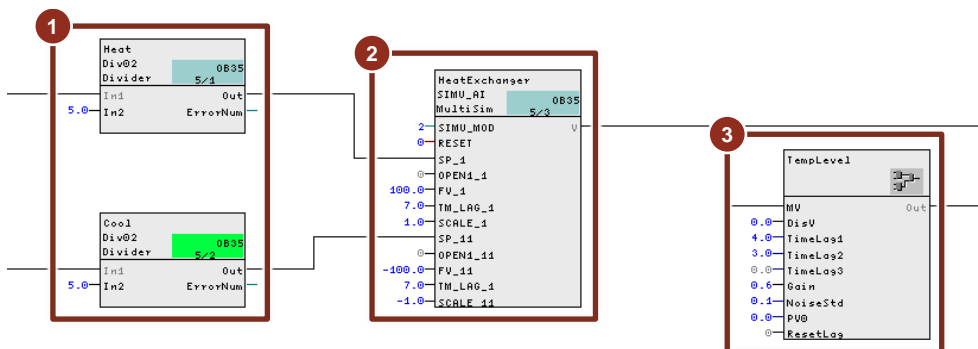
Controller "TIC\_Split" receives the setpoint specification from the master controller and regulates the simulated temperature of a heat exchanger that transfers heat to the inside of the container.

**Structure and parameterization**

**"Sim\_TempLevel" simulation**

In CFC "Sim\_TempLevel", the system simulates a temperature change due to hot steam or cooling water onto the heat exchanger and simulates the internal temperature of the container.

The figure below shows the sequence of the simulation.



1. Reduction of the manipulated variable for simulation. This makes it possible to represent the valve openings of the heating and cooling valves with more emphasis in the trend display.
2. Calculation of the temperature of a heat exchanger. The change in temperature depends on the openings of both valves (a bipolar signal is distributed to the heating steam and cooling water valve) and it is processed after passing through a time-delay block.
3. Internal container temperature that changes depending on the inflow from the heat exchanger. The temperature in the inside of the container is 40 % lower than in the heat exchanger (a factor of 0.6) and it is calculated after passing through two delay elements. The output signal (internal container temperature) has small signal noise.



**NOTE**

Simulation behavior does not correspond to a real process and it is only used to demonstrate the functionality and mode of operation of the "Split range temperature" equipment module. Block "SIMU\_AI" has integrating behavior whereby heating and cooling act with the same intensity. With real heat exchangers, both heat losses into the surroundings and different behavior when heating (e.g. steam) and cooling (e.g. flowing water) are to be expected.

**TIC\_Temp**

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	100.0	Scaling of the process value upper limit
PV_Unit	In	1001	Unit of the process value in degrees Celsius
C	Gain	1.5	Controller gain
C	TI	7.054	Controller lag
C	TD	1.855	Controller differential time
C	SP_InHiLim	100.0	Maximum value of the internal setpoint
to_Actor_Slave	Out		Interconnection to the slave controller (TIC_Split\from_Ctrl.In)
from_Actor_Slave	In		Interconnection to the slave controller (TIC_Split\to_Ctrl.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_TempLevel\TempLevel.Out)

**TIC\_Split**

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Unit	In	1001	Unit of the process value in degrees Celsius
C	Gain	3.5	Controller gain
C	DeadBand	0.2	Width of deadband
C	SP_InHiLim	100.0	Maximum value of the internal setpoint
C	ManLoLim (hidden)	-100.0	Lower limit for the manipulated variable in manual mode
Split range	InScale.High InScale.Low	100.0 -100.0	Marginal range for the input signal
Split range	NeutPos	0.0	Neutral position
Split range	Out1		Interconnection for the simulation (Sim_TempLevel\Cool.In1)
Split range	Out2		Interconnection for the simulation (Sim_TempLevel\Heat.In1)
Split range	Out1Act		Interconnection for the simulation (Sim_TempLevel\HeatExchanger.OPEN1_11)
Split range	Out2Act		Interconnection for the simulation (Sim_TempLevel\HeatExchanger.OPEN1_1)

Block	Connection	Value	Use
to_Actor1	Out		Interconnection to the valve (YC_Heat\from_Ctrl.In)
to_Actor2	Out		Interconnection to the valve (YC_Cool\from_Ctrl.In)
from_Actor1	In		Interconnection to the valve (YC_Heat\to_Ctrl.Out)
from_Actor2	In		Interconnection to the valve (YC_Cool\to_Ctrl.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_TempLevel\HeatExchanger.V)

**NOTE**

The "PID Tuner" program is available for commissioning the "TIC\_Split" controller. At the beginning, experiments for data recording by "PID-Tuner" are conducted in an operating range where only positive values of manipulated variables are expected. After this, a comparable experiment is made in an operating range where only negative manipulated variables occur. If both part transfer functions for heating and cooling show significantly different values for process gain, this must be compensated by a different gradient in both branches of the split range characteristic curve. After the slave controller including the split range has been completely commissioned and tested, the master controller "TIC\_Temp" is optimized using the "PID Tuner" program.

For further information and configuration guidelines, refer to the Online Help for the "CascadeControl" process tag type of the PCS 7 Advanced Process Library.

**YC\_Heat**

The instance has the following parameterization.

Block	Connection	Value	Use
from_Ctrl	In		Interconnection to the controller (TIC_Split\to_Actor1.Out)
to_Ctrl	Out		Interconnection to the controller (TIC_Split\from_Actor1.In)
YC	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)

**YC\_Cool**

The instance has the following parameterization.

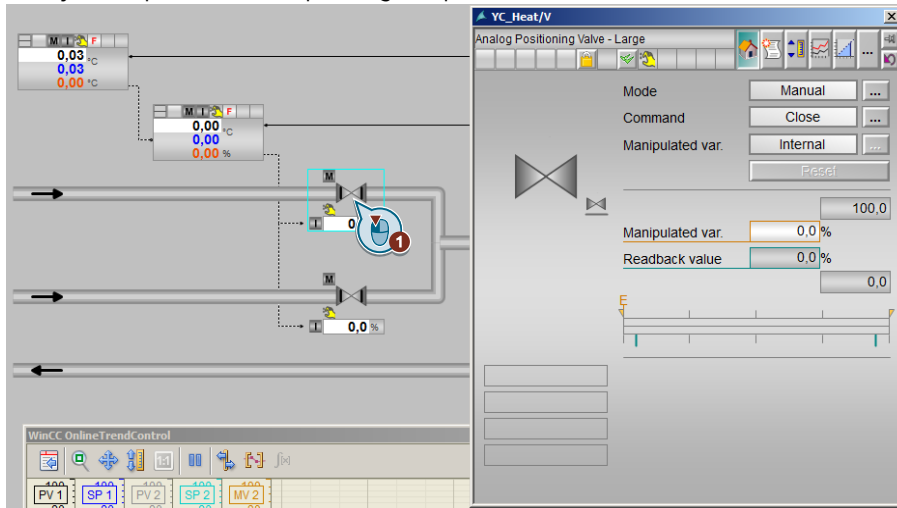
Block	Connection	Value	Use
from_Ctrl	In		Interconnection to the controller (TIC_Split\to_Actor2.Out)
to_Ctrl	Out		Interconnection to the controller (TIC_Split\from_Actor2.In)
YC	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)

## Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

Proceed as follows:

1. Click on the "YC\_Heat" valve module icon.  
The system opens the corresponding faceplate.

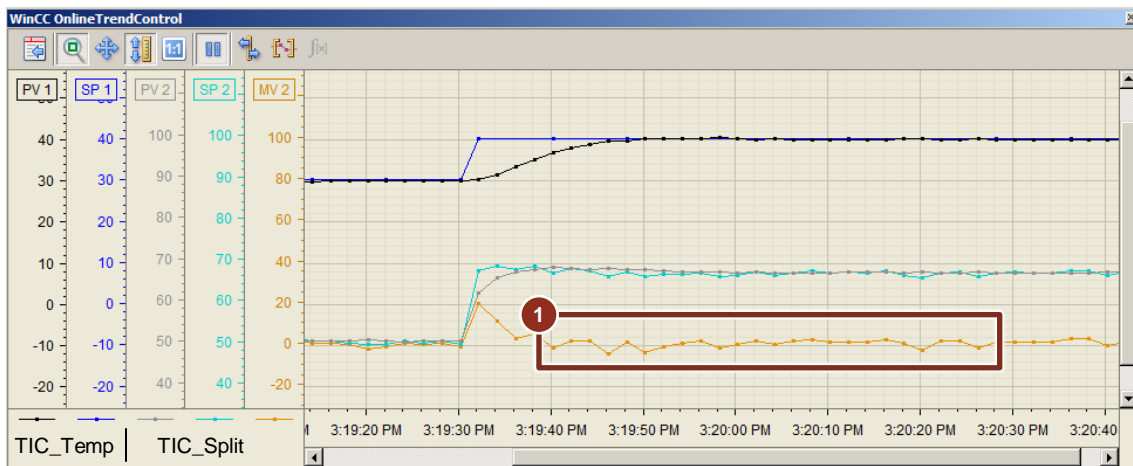


2. In the faceplate, change the operating mode to "Automatic".
3. Switch to "YC\_Cool" valve and change the operating mode to "Automatic".
4. Switch to "TIC\_Split" slave controller, change its operating mode to "Automatic" and the setpoint specification to "External".
5. Switch to "TIC\_Temp" master controller and change the operating mode of the controller to "Automatic".
6. In master controller "TIC\_Temp", enter a setpoint of "30" °C for the operating range.
7. Wait for about one minute and enter a new setpoint of "40" °C.
8. Observe the plotter for about one minute until the new setpoint has been reached.
9. Then click on the "Start/Stop" icon on the toolbar of the OnlineTrendControl.

### NOTE

The motor can be started with the "Start" command on the faceplate.  
In process mode, the motor is controlled via an SFC, e.g. at start-up of the plant.

## Evaluation



After setpoint change SP1, the master controller calculates a manipulated variable MV1 and forwards it in the cascade to the slave controller. This manipulated variable is represented as setpoint SP2 for the slave controller in the curve chart.

The slave controller calculates manipulated variable MV2 from setpoint curve SP2. MV2 acts on the heating and cooling valves and yields temperature curve PV2 of the heat exchanger.

Temperature PV1 in the container follows the temperature of heat exchanger PV2 with a delay.

**Legend**

1

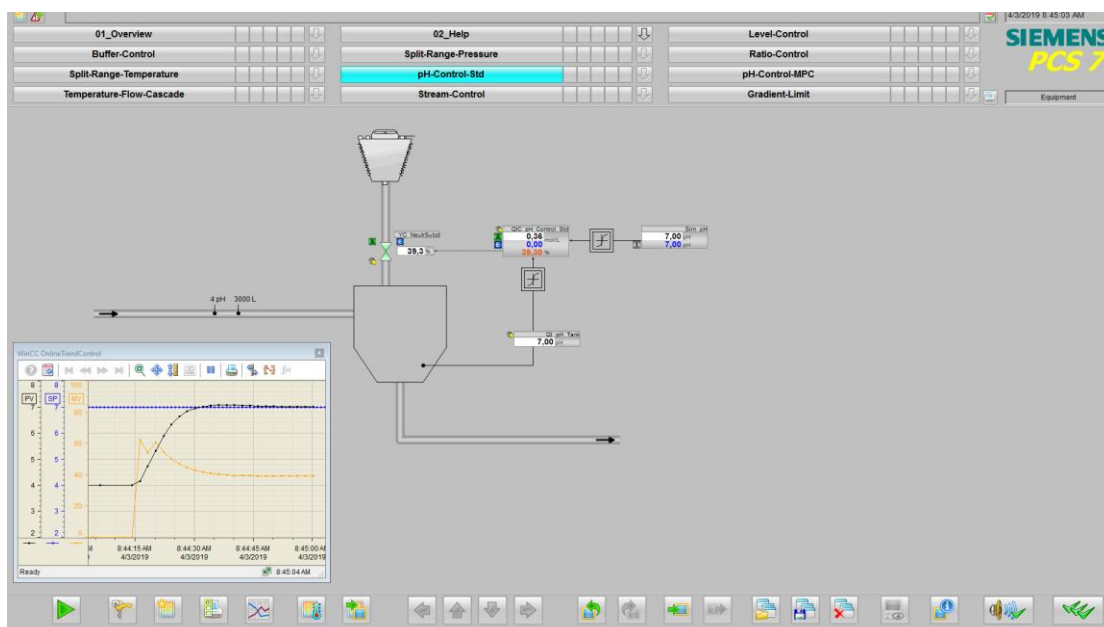
The noise of process variable PV1 leads to noise of manipulated variable MV1 and consequently of setpoint SP2. The oscillation of manipulated variable MV2 in real world applications has to be avoided (e.g. by definition of deadbands) especially around the neutral point of the split-range characteristic, because this means alternating of heating and cooling. In the simulation, the oscillation is actually centered around the neutral point because heat losses into the surroundings are neglected.

## 5.5. pH value control using a standard controller

The pH of the product is set in pH value control "pH-Control-Std". For this, a neutralizer is added to the product in continuous operation to reach the desired pH value.

Due to the highly non-linear titration curve, this means that the gain of the controlled system may fluctuate severely, depending on the operating point. Only for applications in which the pH value is to be kept constant in a very tight range and the disturbances are limited, a simple PID controller with fixed parameterization is sufficient for pH value control. The special feature of the equipment module presented here is the fact that the pH setpoint and the pH process value are converted to concentration differences to achieve linearization of the controlled system characteristic. Unlike the pH value, the difference in concentration between  $\text{OH}^-$  and  $\text{H}_3\text{O}^+$  ions depend in a linear manner on the controller manipulated variable, i.e. on the feed of neutralizing agents. Conversion is carried out based on an inverse titration curve that describes the chemical reaction of the considered process at least approximately. Details on the titration curve can be found in section [6.5](#).

In difficult applications with long dead times (due to the measurement dead time of the pH probe, the time needed for mixing, and the response time of the neutralization reaction) and the need for dynamic feedforward control based on the inflow pH value, we recommend using a predictive controller to compensate the influences.

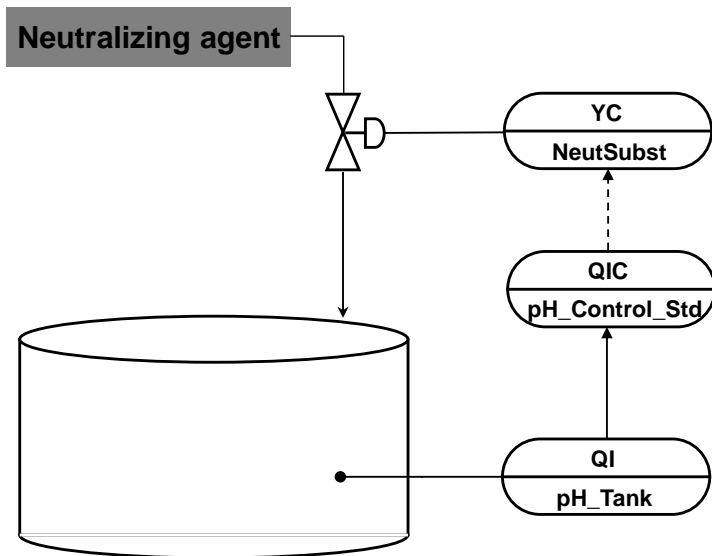


**Overview**

Below, the structure in the P&ID is shown and all of the CMs and the simulation of the equipment module are described.

**P&I Diagram**

The P&ID below symbolically represents all of the components, such as field devices and containers to operation.



**CM and variants**

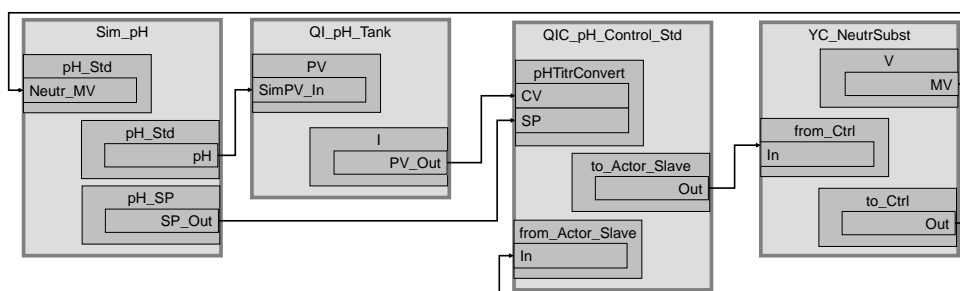
The "pH-Control-h" equipment module consists of three interconnected CMs and one simulation chart. In the simulation chart, the system carries out pH setpoint specification (OpAnL block) and calculates the pH setpoint based on the difference in concentration from the input substance and the neutralizing agent.

The controller gets the converted pH values (setpoint and actual values) as differences in concentration to control.

The following table provides an overview of the CMs of the equipment module including the associated CMTs.

CM	CMT	Selected variants	Description
QI_pH_Tank	MonAn	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale#</li> </ul>	Display of the product pH value-
QIC_pH_Control_Std	PIDCon	<ul style="list-style-type: none"> <li>PV_Scale#</li> </ul>	Standard PID controller without channel blocks for controlling the difference in concentration
YC_NeutSubst	VlvAn	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve for the neutralizing agent

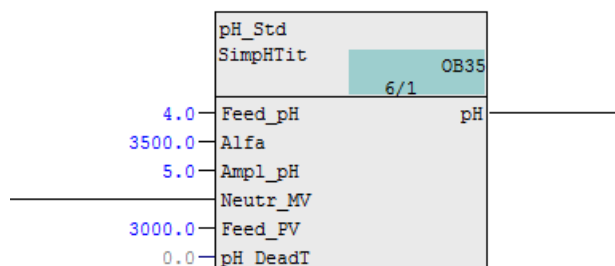
In the figure below, the structure with the cross-chart interconnections is shown in simplified form.



## Structure and parameterization

### "Sim\_pH" simulation

In CFC "pH\_Std" the system calculates the pH value. On sheet 2, there is an OpAnL block to specify the pH setpoint. The following figure shows parameterization of the simulation block.



In the block inputs, fictional parameters are entered for buffer parameter "Alfa" and the "Ampl\_pH" amplitude range that is to be crossed. In addition, fixed values are specified for the pH value and flow amount of input material. No deadtime is set for the pH simulation value (simulation process).

#### NOTE

You can find additional information in Section 6.6 "[Block description of "SimpHTitr"](#)".

### QI\_pH\_Tank

The pH value of the product in the tank is acquired and displayed in the instance. The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	15.0	Scaling of the pH process value upper limit
PV_Unit	In	1422	Unit of the process value as a pH value
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_pH\pH_Std.pH)
PV	SimPV_Out		Interconnection to the controller (QIC_pH_Control_Std\pHTitrConvert.CV)

### QIC\_pH\_Control\_Std

In the instance, the system converts the pH value provided by display "QI\_pH\_Tank" to a concentration difference using block "pHTitrBlock". The concentration difference is used for control. The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale LoScale	10000.0 -10000.0	Scaling of the concentration difference process value limits
PV_Unit	In	1399	Unit of the process value in mol/L (concentration difference)
C	Gain	40.0	Controller gain
C	TI	8.0	Controller lag
C	SP_InHiLim	10000.0	Maximum value of the internal setpoint
C	SP_InLoLim	-10000.0	Minimum value of the internal setpoint
pHTitrBlock			Newly inserted as "pHTitrConvert" to convert pH values to concentration differences

Block	Connection	Value	Use
pHTitrConvert	CV		Interconnection to pH measured value display (QI_pH_Tank\pV_In.PV_Out)
pHTitrConvert	SP		Interconnection to the OpAnL setpoint specification in the simulation chart (Sim_pH\pH_SP.SP_Out)
pHTitrConvert	Alfa	35000	Buffer parameter
pHTitrConvert	Ampl_pH	5.0	The amplitude range that is to be covered
pHTitrConvert	CV_Out		Interconnection to the controller block (C.PV)
pHTitrConvert	SP_Out		Interconnection to the SFC block (IF_SFC.SP_Ext)
to_Actor_Slave	Out		Interconnection to the valve (YC_NeutrSubst\from_Ctrl.In)
from_Actor_Slave	In		Interconnection to the valve (YC_NeutrSubst\to_Ctrl.Out)

**NOTE** You must carry out parameterization of the titration curve for a concrete chemical process before setting the PID controller using the PID tuner. If large variations in the inflow amount of the input materials are to be expected, it is recommend to compensate the disturbance by means of linear manipulated variable conversion using the "pHTitrBlock" block. You can find additional information about converting the pH value into a concentration difference in the block description in Section [6.5](#).

**NOTE** The "PID Tuner" program is available for commissioning controller "QIC\_pH\_Control\_Std". The system first records data for the "PID-Tuner" in an operating range in which only positive manipulated variables occur. After this, a comparable experiment is made in an operating range in which only negative manipulated variables occur. Optimization of the pH value-control was carried out based on the concentration difference using different manipulated variables (MV) with a constant (input material) inflow amount.

**NOTE** The following messages of the measurement "QI\_pH\_Tank" are not displayed in the controller:

- for hardware fault (CSF)
- device being maintained (OosLi)

If they are needed, interconnect them additionally with blocks "CSF" and "OosAct" in chart partition "B" sheet 3.

Alternatively, you can activate the "to\_Indicate" option in the display process tag and add an appropriate "from\_Indicate" link block to the Ctrl CMT and interconnect it appropriately. As an example, you can use the "ModPreCon" CMT as a guide.

### YC\_NeutrSubst

The instance has the following parameterization.

Block	Connection	Value	Use
V	MV		Interconnection for the simulation (Sim_pH\pH_Std.Neutr_MV)
from_Ctrl	In		Interconnection to the controller (QIC_pH_Control_Std\to_Actor_Slave.Out)
to_Ctrl	Out		Interconnection to the controller (QIC_pH_Control_Std\from_Actor_Slave.In)
MV_Out	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)

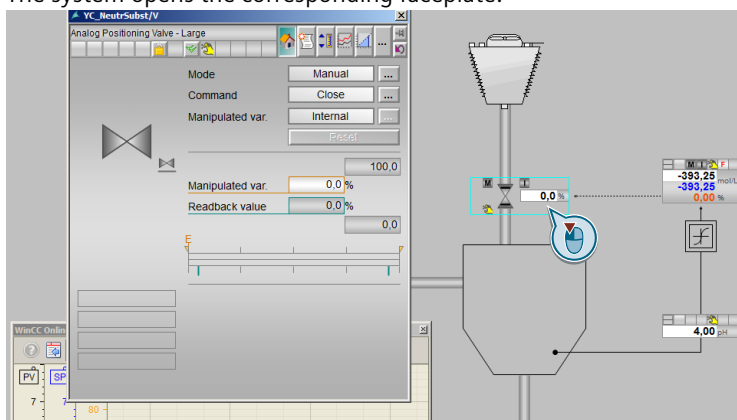


## Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

Proceed as follows:

1. Click on the symbol display of the "YC\_NeutrSubst" valve.  
The system opens the corresponding faceplate.



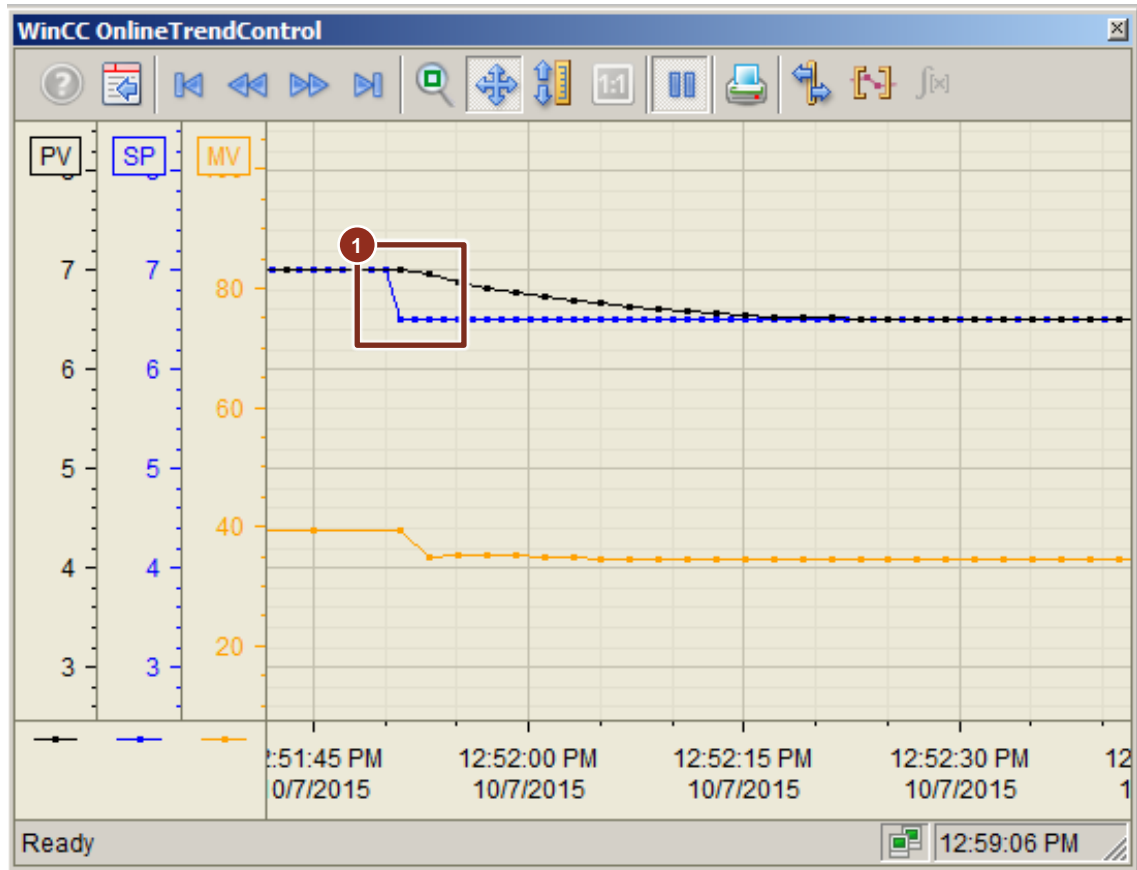
2. In the faceplate, change the operating mode to "Automatic".
3. Switch to controller "QIC\_pH\_Control\_Std" and change the operating mode of the controller to "Automatic" and the setpoint specification to "External".

### NOTE

The controller uses the preset pH value of the OpAnL symbol display as the setpoint. In this symbol display, 7 pH is set as the setpoint (neutral zone) based on which the amount of neutralizing agent is fed (regulated).

4. Wait for about 2 minutes until the process value reaches its specified operating range.
5. Switch to operator control block "pH\_SP" and specify a new setpoint of 6.5 pH.
6. Close the faceplate and observe the plotter for about one minute until the new setpoint has been reached.

## Evaluation



The controller is optimized without overshooting to reach the setpoint. After changing the setpoint, the controller regulates the addition of neutralizer with a slight delay.

**NOTE**

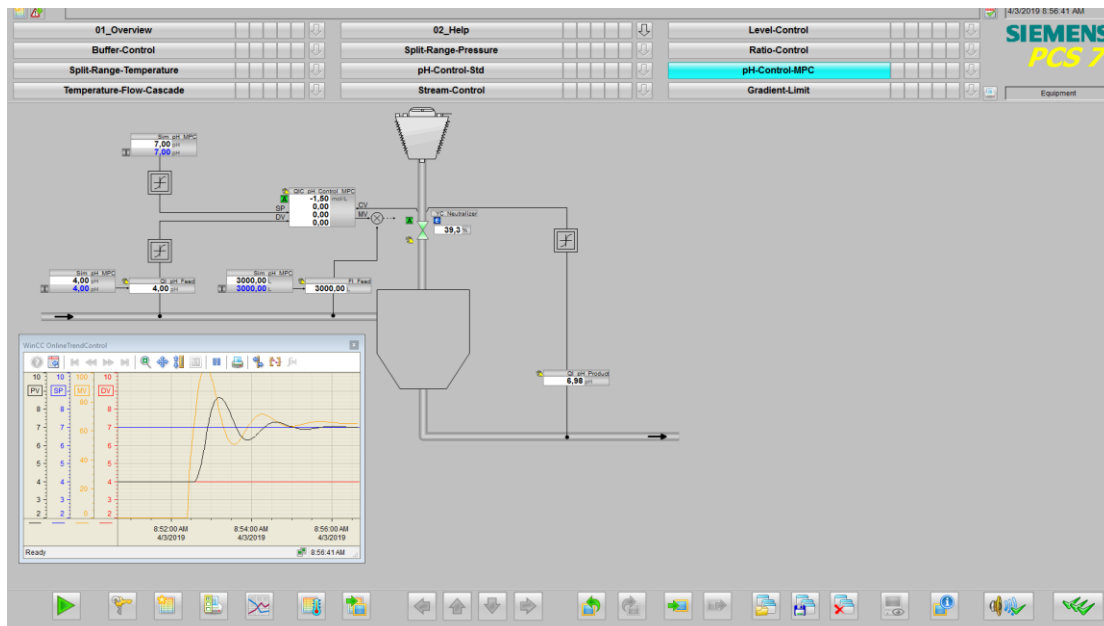
The controller is set for an operating point of  $\pm 0.5$  pH around the neutral zone 7 pH. Under some circumstances, different operating points may make it necessary to optimize the controller again.

## 5.6. pH value control using predictive controller

pH value control using a "pH-Control-MPC" model predictive controller is used for the same tasks with the special features due to the highly non-linear titration characteristic curve. In addition to pH value control using standard controller, the MPC allows targeted compensation of dead times of the controlled system (due to the measurement dead time for mixing, and the reaction time of the neutralization reaction) as well as model-based compensation of measurable disturbances due to fluctuations of the pH value in the inflow.

In the following example of pH value control by addition of a neutralizing agent, we will consider the pH value and feed flow of the input material besides the pH value in the tank.

The example is designed for continuous operation and it is possible to modify the pH value and the inflow of the input material.

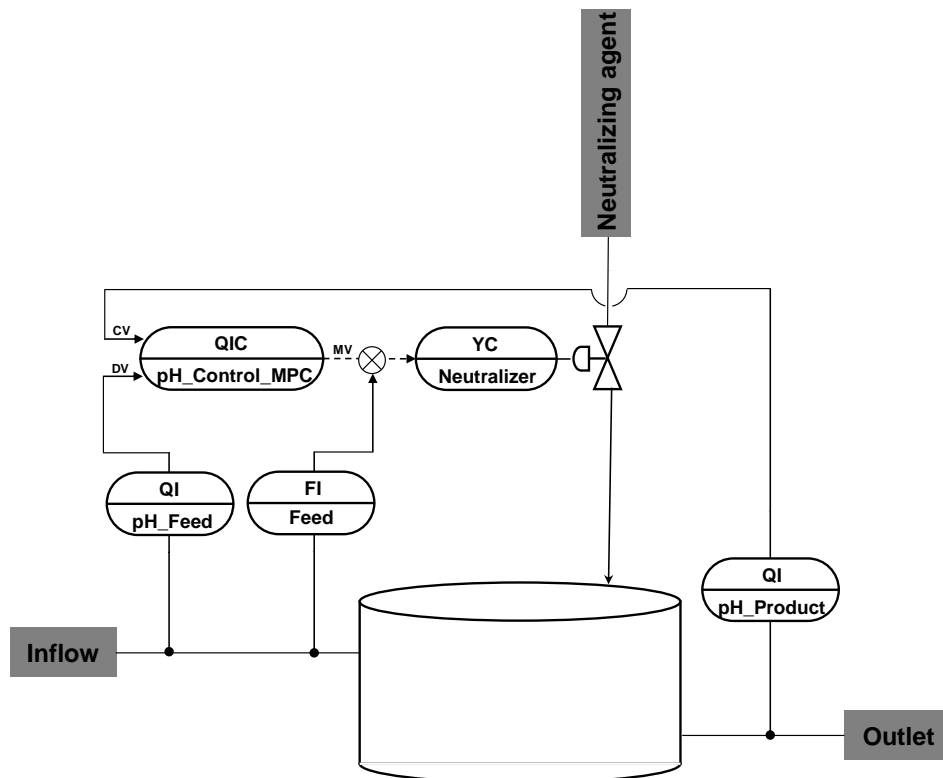


## Overview

Below, the structure in the P&ID is shown and all of the CMs and the simulation of the equipment module are described.

## P&I Diagram

The P&ID below symbolically represents all of the components, such as units and containers, etc. relevant to operation.



## CM and variants

The "pH-Control-MPC" equipment module consists of five interconnected CMs and one simulation chart. In the simulation chart, the pH value of the product is determined from the pH value and the inflow amount of the input material and of the neutralizer (manipulated variable of the valve).

Operators can adapt in the OS the pH value for the input material and the pH setpoint as well as the inflow amount. For this, OpAnL blocks have been inserted in the simulation chart and the controller process tag.

For regulation, the controller uses the converted pH values (setpoint and actual values of the product and actual value of the input material) as concentration differences. In addition, the inflow amount of the input material affects the inflow amount of the neutralizer, since the maximum manipulated variable changes proportionally to the factor from the actual inflow amount and the maximum inflow amount of the input material.

**NOTE** Additional information about calculating the manipulated variable or scaling in the block description can be found in Section [6.5](#).

You specify the values below in the OpAnL blocks and can adjust them in the Operator Station:

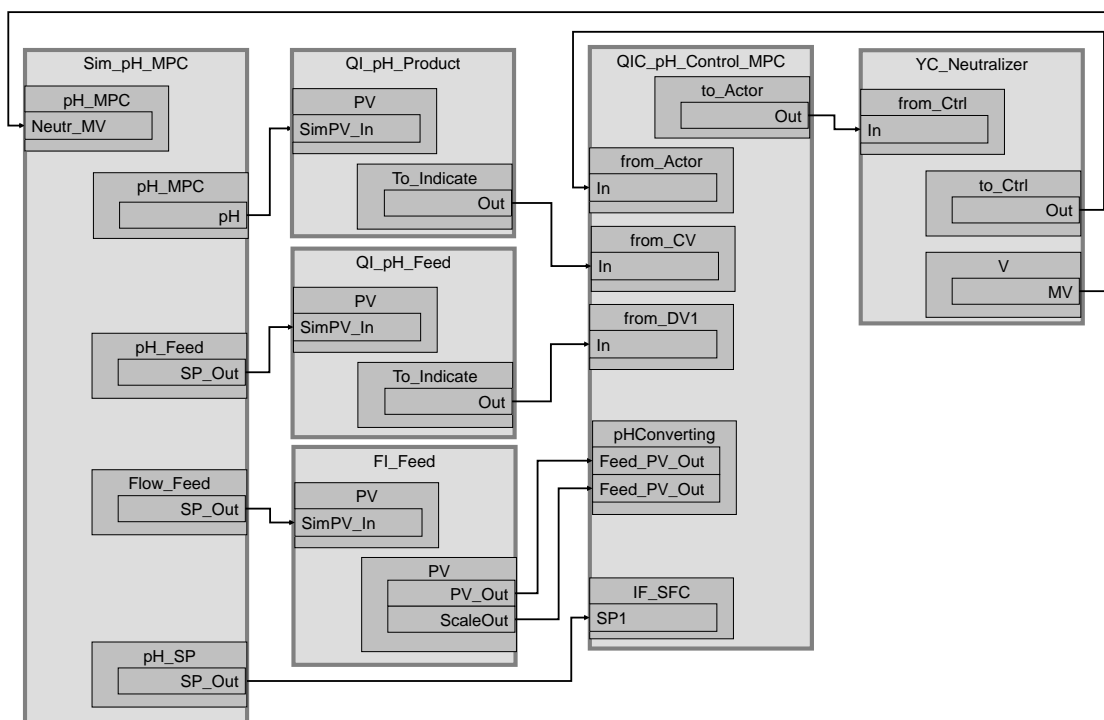
- pH setpoint (product)
- pH value of the input material
- inflow amount of the input material

To simplify the project, an additional display process tag was not implemented for each value specification.

The following table provides an overview of the CMs of the equipment module including the associated CMTs.

CM	CMT	Selected variants	Description
QIC_pH_Control_MPC	ModPreCon4Valve	<ul style="list-style-type: none"> <li>•</li> </ul>	Multivariable controller for regulating the pH value of the product
QI_pH_Product	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale#</li> <li>• To_Indicate</li> </ul>	Display of the pH value of the product
QI_pH_Feed	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale#</li> <li>• To_Indicate</li> </ul>	Display of the pH value of the input material
FI_Feed	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale#</li> </ul>	Throughflow display of the input material
YC_Neutralizer	VlvAn	<ul style="list-style-type: none"> <li>• IF_Ctrl#</li> <li>• MV_Scale#</li> <li>• RbkReturn</li> <li>• YC</li> </ul>	Control valve for the neutralizing agent

In the figure below, the structure with the cross-chart interconnections is shown in simplified form.

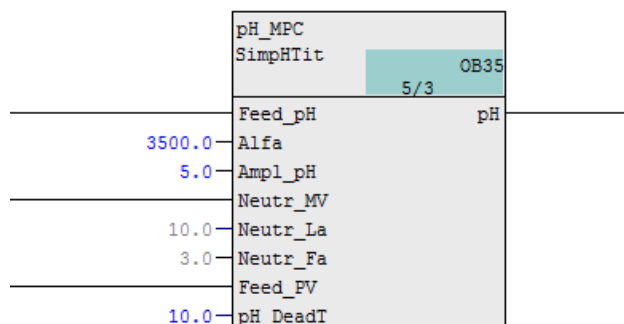


Multivariable controller "QIC\_pH\_Control\_MPC" acquires the pH value of the input material, the pH value of the draining product, and the pH setpoint as concentration differences. Depending on the pH difference (setpoint and actual value of the product), the system feeds the necessary amount of neutralizer to the tank via control valve "YC\_Neutralizer".

**Structure and parameterization**

**Simulation "Sim\_pH\_MPC"**

In CFC "Sim\_pH\_MPC" the system calculates the pH value. On sheet 2, there is an OpAnL block to specify the pH setpoint, the pH value, and the inflow amount of the input material. The following figure shows parameterization of the simulation block.



In the block inputs, fictional parameters are entered for buffer parameter "Alfa" and the "Ampl\_pH" amplitude range that is to be crossed. In addition, the manipulated variable of control valve "YC\_Neutralizer" and the inflow amount of the input material (OpAnL block on sheet 2) are used for the calculation.

A deadtime of 10 seconds, a neutralizer inflow delay of 10 seconds, and a gain factor of 3 are set for the pH simulation value (simulation process).

**NOTE** You can find additional information in the block description in Section [6.5](#).

### QI\_pH\_Product

The pH value of the product is acquired and displayed in the instance. The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	15.0	Scaling of the pH process value upper limit
PV_Unit	In	1422	Unit of the process value as a pH value
to_Indicate	Out		Interconnection to the multivariable controller (QIC_pH_Control_MPC\from_CV.In)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_pH_MPC\pH_MPC.pH)

### QI\_pH\_Feed

The pH value of the input material is acquired and displayed in the instance. The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	15.0	Scaling of the pH process value upper limit
PV_Unit	In	1422	Unit of the process value as a pH value
to_Indicate	Out		Interconnection to the multivariable controller (QIC_pH_Control_MPC\from_DV1.In)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_pH_MPC\pH_Feed.SP_Out)

### FI\_Feed

The amount of the input material is acquired and displayed in the instance. The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	5000.0	Scaling of the amount
PV_Unit	In	1038	Process value unit in L (liters)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_pH_MPC\Flow_Feed.SP_Out)
PV	PV_Out		Interconnection to the multivariable controller (QIC_pH_Control_MPC\pHConverting.Feed_PV_Out)
PV	Scale_Out		Interconnection to the multivariable controller (QIC_pH_Control_MPC\pHConverting.Feed_Scale)

### QIC\_pH\_Control\_MPC

In the multivariable controller, the system converts the pH value provided by display "QI\_pH\_Product" to a concentration difference using block "pHTitrBlock". The concentration difference is used for control. In the same way, the system converts the setpoint specification as well as the pH value of the input material disturbance variable to a concentration difference.

The instance has the following changes and parameterization.

Block	Connection	Value	Use
MPC	CV1		Existing interconnection deleted. New interconnection to the conversion block (pHConverting.CV_Out)
MPC	DV1		Existing interconnection deleted. New interconnection to the conversion block (pHConverting.DV_Out)
MPC	SP1		Existing interconnection deleted. New interconnection to the conversion block (pHConverting.SP_Out)
MPC	SP1HiLim	500	Upper setpoint limit for the concentration difference
MPC	SP1LoLim	-500	Lower setpoint limit for the concentration difference
MPC	MV1HiLim		Existing interconnection deleted. New interconnection to the conversion block (pHConverting.MVHiLim)
MPC	CV1_Unit	1399	Existing interconnection deleted. Unit of measurement for the controlled variable in mol/L (process value)
MPC	DB_No	50	Data block with controller data
MPC	MV1		Existing interconnection deleted. New interconnection to the conversion block (pHConverting.MV)
pHTitrBlock			Newly inserted as "pHConverting" to convert pH values
pHConverting	CV		New interconnection to the link block (from_CV.ReStru1)
pHConverting	DV		New interconnection to the link block (from_DV1.ReStru1)
pHConverting	SP		New interconnection to the IF_SFC block (IF_SFC.SP1Out)

Block	Connection	Value	Use
pHConverting	MV		New interconnection from controller block (MPC.MV1)
pHConverting	Feed_PV_Out		New interconnection from throughflow display of the input material (FI_Feed\pV_In.PV_Out)
pHConverting	Feed_Scale		New interconnection from throughflow display of the input material (FI_Feed\pV_In.ScaleOut)
TitrConverting	CV_Out		Interconnection to the controller block (MPC.CV1)
TitrConverting	DV_Out		Interconnection to the controller block (MPC.DV1)
TitrConverting	SP_Out		Interconnection to the controller block (MPC.SP1)
TitrConverting	MVHiLim		Interconnection to the controller block (MPC.MV1HiLim)
TitrConverting	MV_Valve		Interconnection to the communication block (to_Valve.ReStru1)
IF_SFC	SP1		Interconnection of OpAnL block for setpoint specification (Sim_pH_MPC\pH_SP.SP_Out)
to_Actor	Out		Interconnection to the valve (YC_Neutralizer\from_Ctrl.In)
from_Actor	In		Interconnection to the valve (YC_Neutralizer\from_Ctrl.Out)

**NOTE**

The multivariable controller was optimized using the MPC configurator for an operating range from 7.5 to 6.5 pH and stored in DB 50. The relevant influencing variables were an inflow amount of the input material of 3000 L/s with pH 4 and a neutralizing agent with a pH of 12.

For trend recording, the manipulated variable was excited using the "AutoExci" block and the disturbance variable was changed ( $\pm 10\%$ ).

**YC\_Neutralizer**

The instance has the following parameterization.

Block	Connection	Value	Use
V	MV		Interconnection for the simulation (Sim_pH_MPC\pH_MPC.Neutr_MV)
from_Ctrl	In		Interconnection to the controller (QIC_pH_Control_MPC\to_Actor.Out)
to_Ctrl	Out		Interconnection to the controller (QIC_pH_Control_MPC\from_Actor.In)
MV_Out	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)

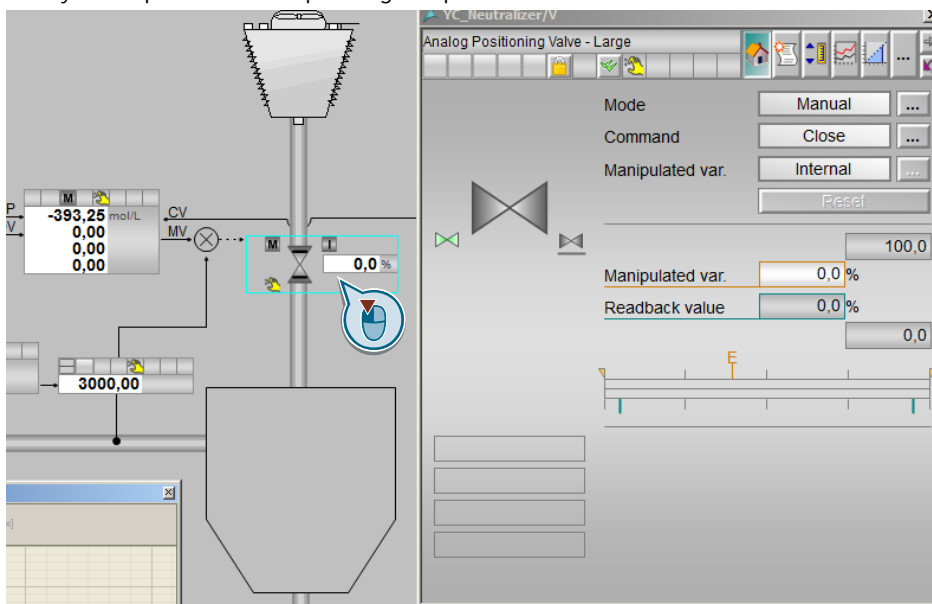


### Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

Proceed as follows:

1. Click on the symbol display of the "YC\_Neutralizer" valve.  
The system opens the corresponding faceplate.

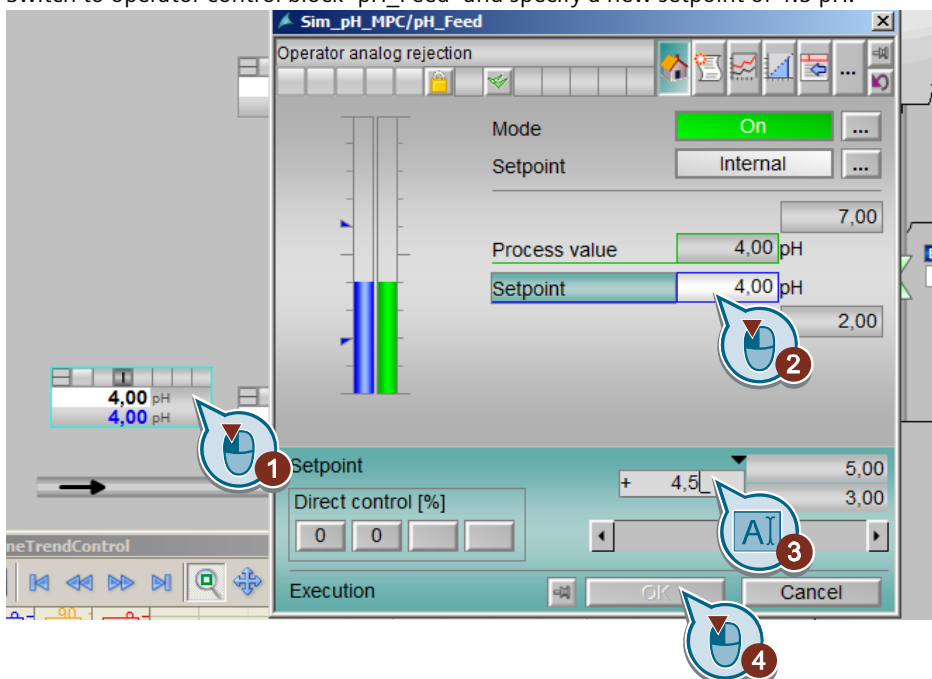


2. In the faceplate, change the operating mode to "Automatic".
3. Switch to controller "QIC\_pH\_Control\_MPC" and change the controller's operating mode to "Automatic".

**NOTE**

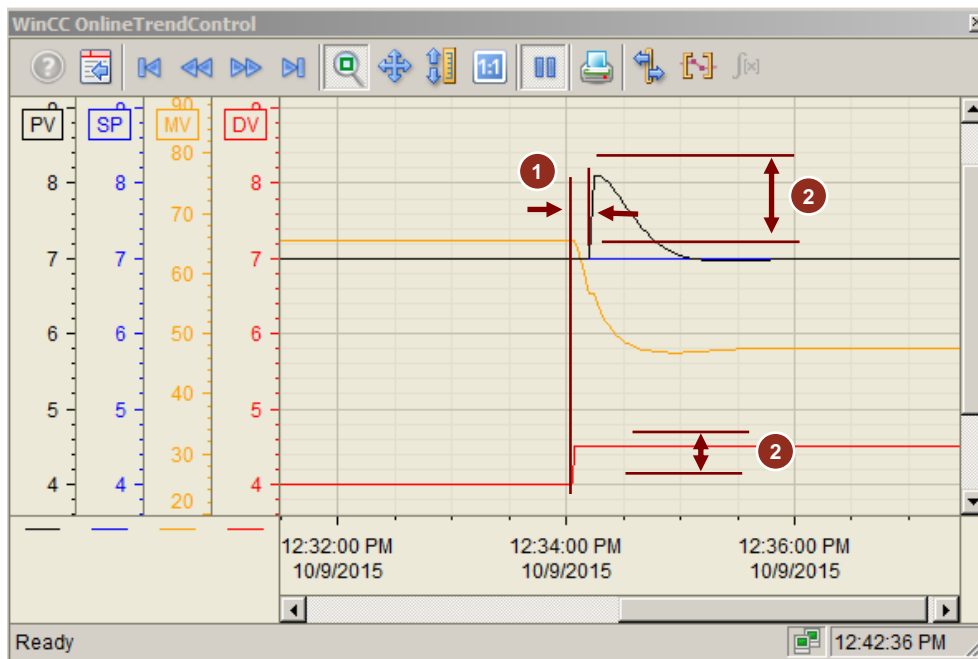
The controller uses the preset pH value of the OpAnL symbol display as the setpoint. In this symbol display, 7 pH is set as the setpoint (neutral zone) based on which the amount of neutralizing agent is fed (regulated).

4. Wait for about 1 minute until the process value reaches its specified operating range.
5. Switch to operator control block "pH\_Feed" and specify a new setpoint of 4.5 pH.



6. Close the faceplate and observe the plotter for about one minute until the new setpoint has been reached.

## Evaluation



1. The controller is optimized to reach the setpoint exactly and consequently, slowly. The controller detects the change in the disturbance variable and it modifies the manipulated variable before the process responds to influencing of the disturbance variable (set deadtime in the simulation block). The disturbance variable acts on the actual value without delay (time delay elements).
2. In the example, the pH value of the input material was increased by 0.5 pH; however, it had an effect of about 1 pH on the product.

Despite detecting the disturbance variable in good time, the controller needs about 90 seconds for compensation and regulation. This time is also needed for control with bigger changes in the pH value of the input material.

## 5.7. "Temperature-Flow-Cascade"

Temperature control via flow controller for a service medium (e.g. heating steam, cooling water, or fuel) in cascade structure is used for applications in which fluctuations within the auxiliary control loop (of the flow controller) have to be compensated quickly, or the slave controller can compensate other unpleasant properties of the actuator (e.g. a non-linear valve characteristic curve) which are therefore invisible for the master controller. Temperature flow cascades are used for heat exchangers, reactors or burners, for example.

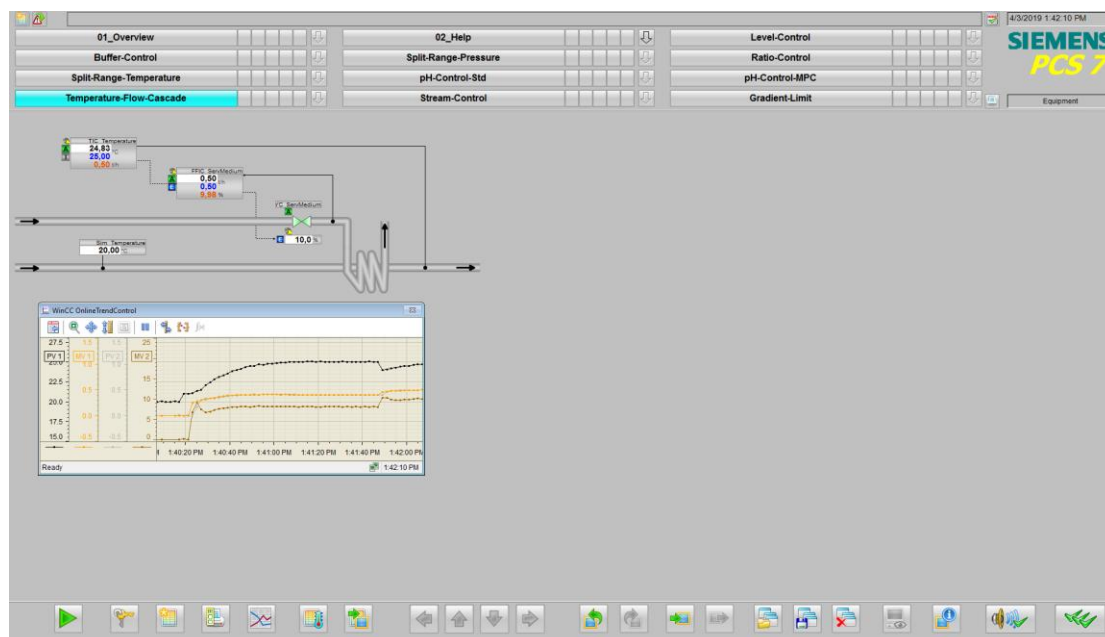
In the heat exchanger, the system continuously pumps the contents of the container through the heat exchanger via piping. This heats up or cools the product material to a defined temperature by means of thermal transfer from the service medium.

The same control concept is used with a burner, i.e. the amount of fuel flow regulates the temperature.

### NOTE

The "temperature flow cascade" equipment module can be used for any process applications where temperature control is carried out via flow.

In the following example, we will consider temperature control on a heat exchanger that is heated by means of a heating medium. It is also possible to use heat exchangers to cool a material flow. In this case, the flow of cooling medium is manipulated instead of heating medium. The usual generic term for a heating or cooling medium is "service medium". The controller structure of heat exchangers does not depend on whether they are used for heating or cooling. The only change is the sign of the master controller's controlled system.

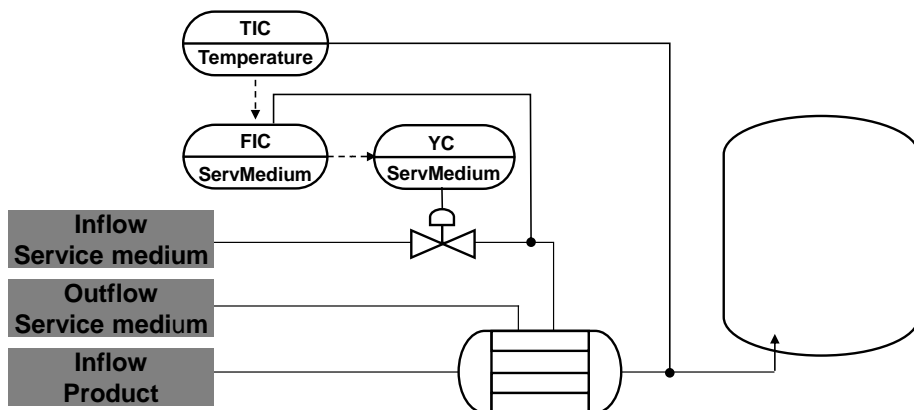


**Overview**

Below, the structure in the P&ID is shown and all of the CMs and the simulation of the equipment module are described.

**P&I Diagram**

The P&ID below symbolically represents all of the components, such as units and containers, etc. relevant to operation.



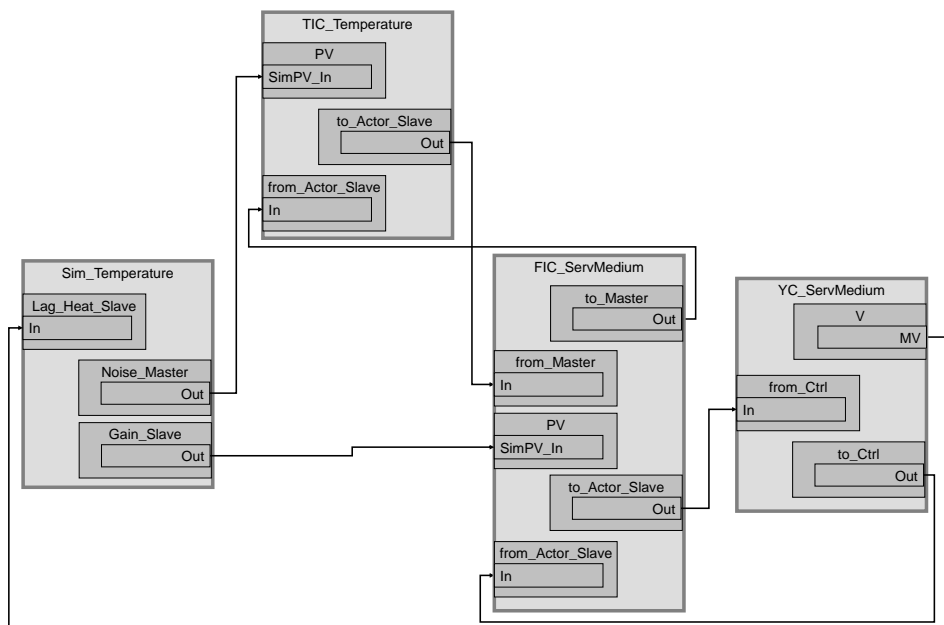
**CM and variants**

The "temperature flow cascade" equipment module consists of three interconnected CMs and one simulation chart. The simulation chart simulates the effect of the heat exchanger on the input material temperature.

The following table provides an overview of the CMs of the equipment module including the associated CMTs.

CM	CMT	Selected variants	Description
TIC_Temperature	PIDCon	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale#</li> </ul>	Master controller for temperature control
FFIC_ServMedium	PIDCon	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>PV</li> <li>PV_Scale#</li> </ul>	Slave controller for the flow control
YC_ServMedium	VlvAn	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve for the heating medium

In the figure below, the structure with the cross-chart interconnections is shown in simplified form.

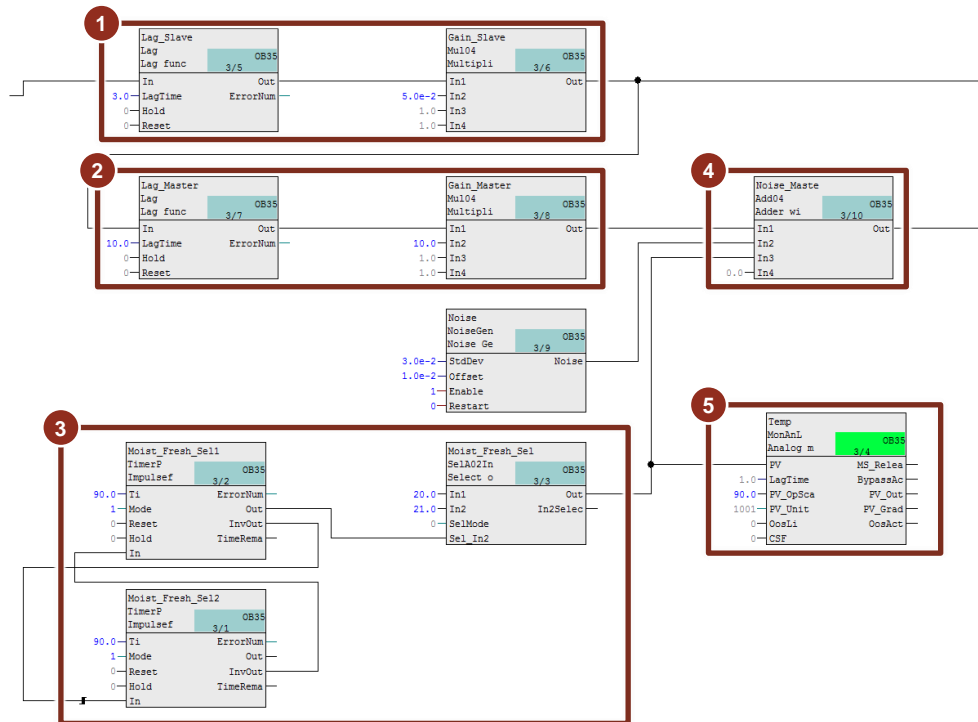


Controller "TIC\_Temperature" uses the temperature of a material to be regulated from the "Sim\_Temperature" simulation chart and generates the setpoint specification for the slave controller. This means that the desired temperature curve is configured in process tag "TIC\_Temperature". Slave controller "FIC\_ServMedium" regulates the flow rate of the heating medium by means of control valve "YC\_ServMedium" based on the setpoint specification of the master controller.

### Structure and parameterization

#### "Sim\_Temperature" simulation

In CFC "Sim\_Temperature", the system simulates a temperature change of a material by a heat exchanger. The figure below shows the sequence of the simulation.



1. If a valve is 100 % open, with a 3-second delay, a flow of 5 t/h (factor 0.05) is sent to the slave controller as the flow rate actual value.
2. With a 10-second delay (as a simulation for heating up of the thermal capacity of the heat exchanger), ten times the value of the heating steam flow rate is sent to the reference junction as the actual value of the hot air temperature.
3. Alternating input material temperature that changes every 90 seconds between 20 °C and 21 °C to simulate a disturbance.
4. Input material temperature for the master controller that changes in dependence on the heat exchanger. The output signal can be given slight signal noise.
5. Material temperature before being heated by the heat exchanger.

#### NOTE

Simulation behavior does not correspond to a real process and it is only used to demonstrate the functionality and mode of operation of the "temperature flow cascade" equipment module.

#### TIC\_Temperature

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	200.0	Scaling of the process value upper limit
PV_Unit	In	1001	Unit of the process value in degrees Celsius
C	TI	7.3	Controller lag
C	SP_InHiLim	200.0	Maximum value of the internal setpoint

Block	Connection	Value	Use
to_Actor_Slave	Out		Interconnection to the slave controller (FIC_ServMedium\from_Ctrl.In)
from_Actor_Slave	In		Interconnection to the slave controller (FIC_ServMedium\to_Ctrl.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_Temperature\Noise_Master.Out)

### FIC\_ServMedium

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	10.0	Scaling of the process value upper limit
PV_Unit	In	1328	Unit of the process value in t/h (tons per hour)
C	Gain.Value	2.8	Controller gain
C	TI	1.7	Controller lag
C	SP_InHiLim	10.0	Maximum value of the internal setpoint
to_Actor_Slave	Out		Interconnection to the control valve (YC_ServMedium\from_Ctrl.In)
from_Actor_Slave	In		Interconnection to the control valve (YC_ServMedium\to_Ctrl.Out)
to_Master	Out		Interconnection to the master controller (TIC_Temperature\from_Actor_Slave.In)
from_Slave	In		Interconnection to the master controller (TIC_Temperature\to_Actor_Slave.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_Temperature\Gain_Slave.Out)

#### NOTE

The "PID Tuner" program is available for commissioning the controller. Please remind that you optimize the slave controller (service medium flow) first, and then the master temperature controller.

### YC\_ServMedium

The instance has the following parameterization.

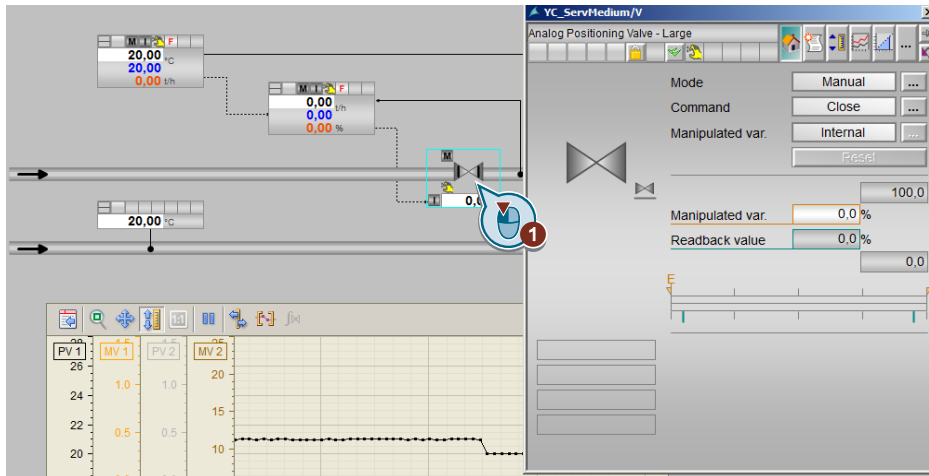
Block	Connection	Value	Use
V	MV		Interconnection for the simulation (Sim_Temperature\Lag_Slave.In)
from_Ctrl	In		Interconnection to the controller (FIC_ServMedium\to_Actor_Slave.Out)
to_Ctrl	Out		Interconnection to the controller (FIC_ServMedium\from_Actor_Slave.In)
MV_Out	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)

## Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

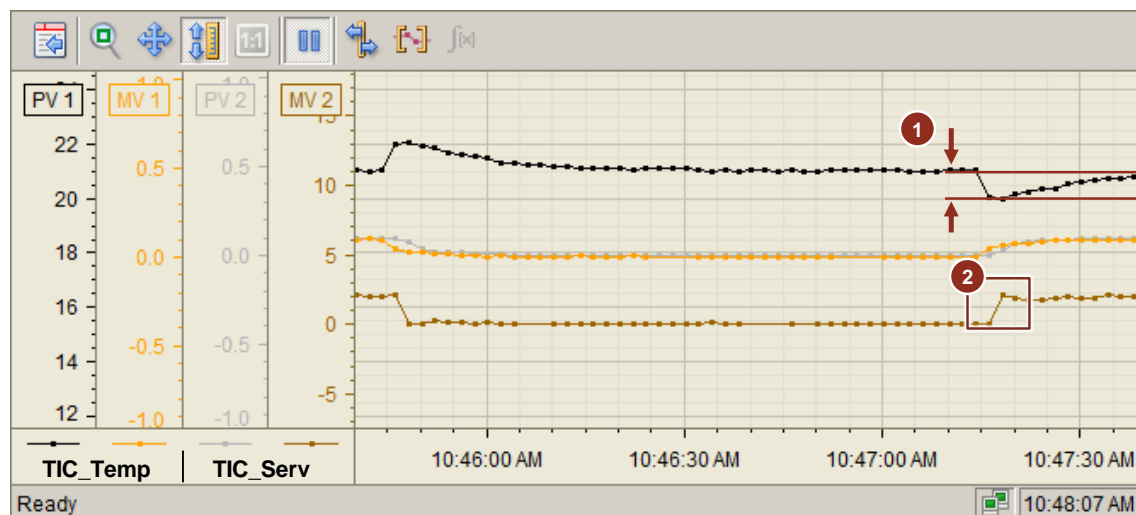
For commissioning, proceed as follows:

1. Click on the symbol display of the "YC\_ServMedium" valve.  
The system opens the corresponding faceplate.



2. In the faceplate, change the operating mode to "Automatic".
3. Switch to slave controller "FIC\_ServMedium", change its operating mode to "Automatic" and the setpoint specification to "External".
4. Switch to master controller "TIC\_Temperature" and change the operating mode of the controller to "Automatic".
5. Enter a new setpoint of 21 °C in master controller "TIC\_Temperature".
6. Wait for about 2 minutes and then click on the "Start/Stop" icon on the toolbar of the OnlineTrendControl.

## Evaluation



1. The temperature of the product medium changes every 90 seconds. The master controller responds to this change and regulates towards the temperature setpoint of 21 °C.
2. On detecting a temperature change, the master controller transfers a new setpoint to the slave controller. The slave controller responds directly to this change with a new setpoint (brown trend display) and tracks the process value (gray trend display) to the setpoint (orange trend display).

The slave controller (flow of the heating medium in t/h) is configured for exact control without overshooting.

## 5.8. Coarse-/Finestream-Control "Stream-Control"

In some process operating modes (start-up, production operation, load changes, etc.), it is necessary to control large flow rates very precisely. In these situations, two valves are used, since the control ratio of continuous valves for flow rates in pipelines is limited. Typically, the maximum flow rate cannot be more than 50 times greater than the minimum controllable flow rate.

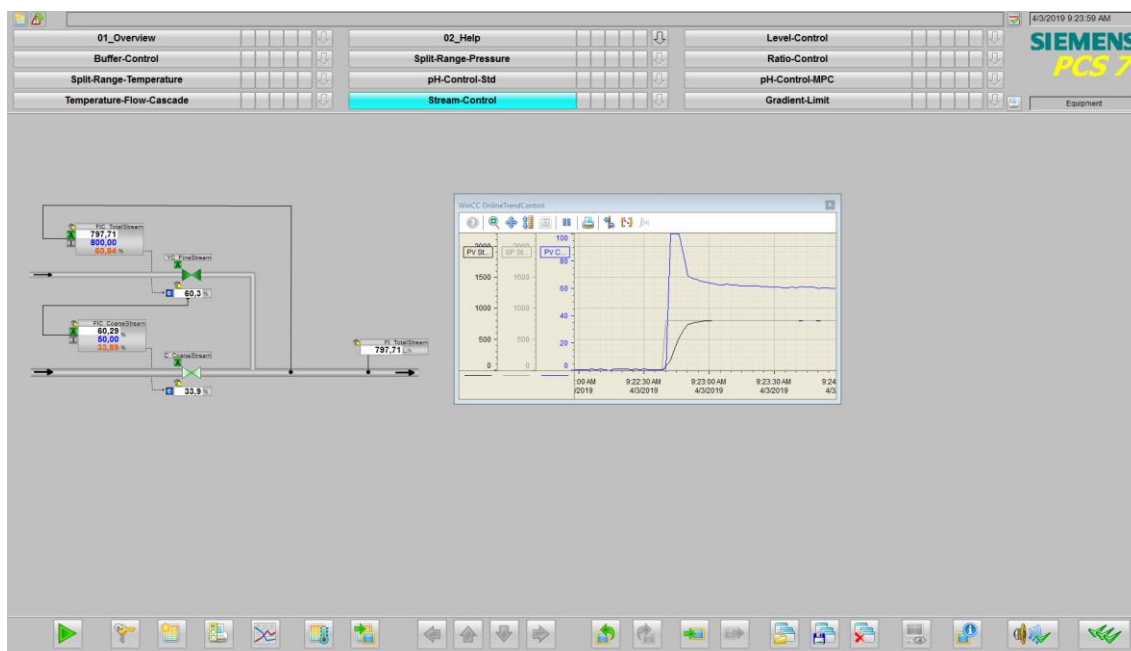
A large valve in a pipeline of great diameter controls the larger percentage of the material flow. However, the large valve cannot dose very precisely and also reacts relatively slowly. A thinner pipe with a smaller valve acts in parallel; it can dose more exactly and can control faster. Downstream of the valves, the two pipes are joined again to maintain the desired overall flow.

The task of a coarse/fine flow control scheme is to control the two valves in such a way that the requirements regarding the control range, precision, and dynamics of the total flow are met.

Typical fields of application are:

- Quality control in chemical processes, such as pH control with flow control of the neutralizing agent.
- Temperature controls on distillation towers or reactors with flow control of the heating/cooling medium.
- Provision of auxiliary energy (heating steam, compressed air) for process plants, e.g. with a large and a small steam generator or a large and a small compressor.

The fine flow controller uses the overall flow as controlled variable. The coarse flow controller uses as its controlled variable the position of the control valve for the fine flow, with a setpoint of 50 % and a relatively broad deadband. The aim of the coarse flow controller is to roughly adjust the main mass flow so that the fine flow controller remains in the middle of its working range and can perform the fine regulation.



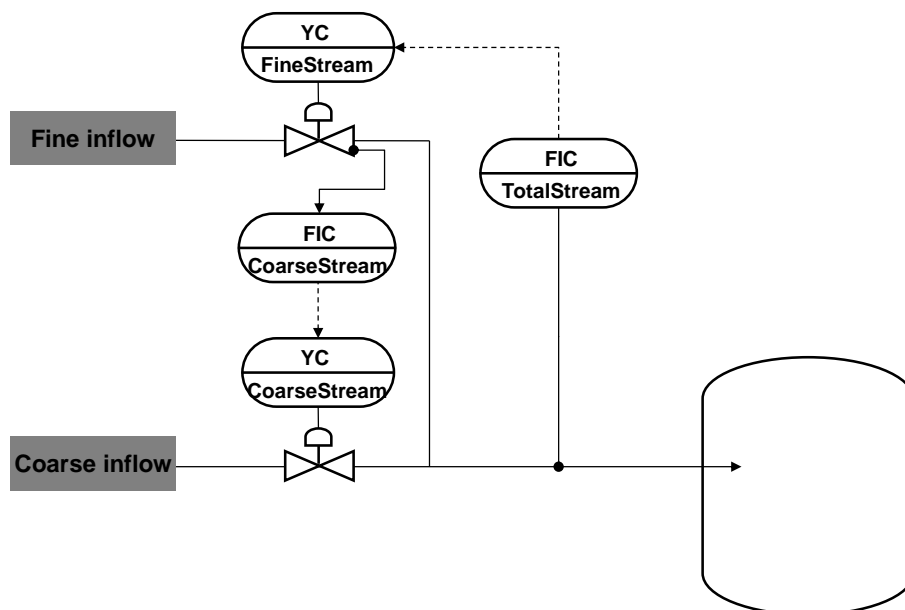


## Overview

Below, the structure in the P&ID is shown and all of the CMs and the simulation of the equipment module are described.

## P&I Diagram

The P&ID below symbolically represents all of the components, such as field devices and pipes, relevant to operation.



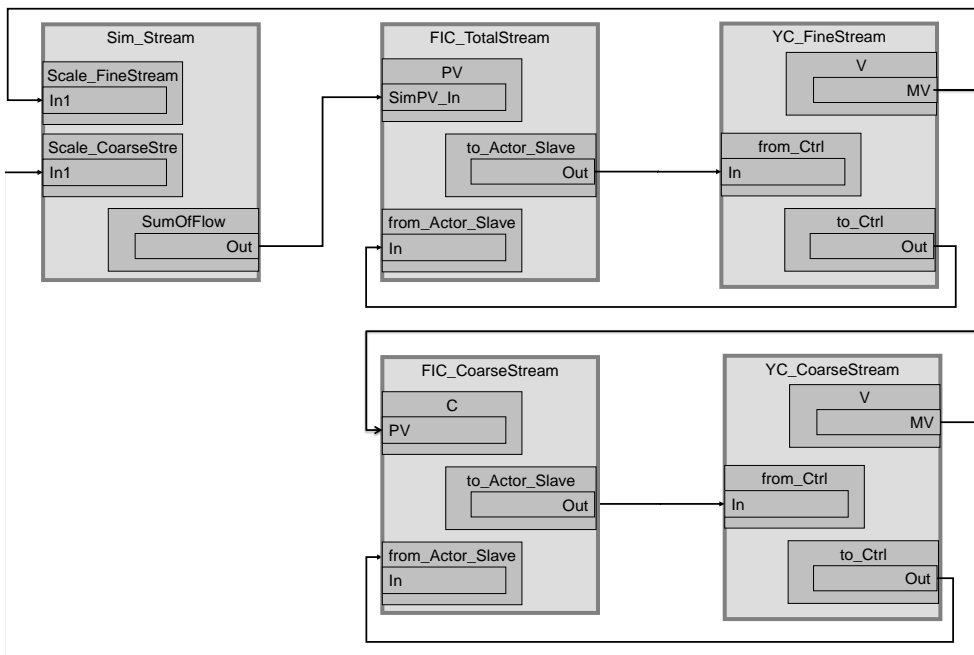
## CM and variants

The "Stream Control" equipment module consists of four connected CMs and one simulation chart. On the simulation chart, the system forms the total from the two inflows (fine and coarse inflow).

The following table provides an overview of the CMs of the equipment module, including the associated CMTs.

CM	CMT	Selected variants	Description
FIC_TotalStream	PIDCon	<ul style="list-style-type: none"> <li>PV_Scale#</li> </ul>	Throughflow control of fine stream
YC_FineStream	VlvAn	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve for the fine stream
FIC_CoarseStream	PIDCon	<ul style="list-style-type: none"> <li>PV_Scale#</li> </ul>	Throughflow control of coarse stream with acquisition of the manipulated value from the fine stream valve
YC_CoarseStream	VlvAn	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve for the coarse stream

In the figure below, the structure with the cross-chart interconnections is shown in simplified form.



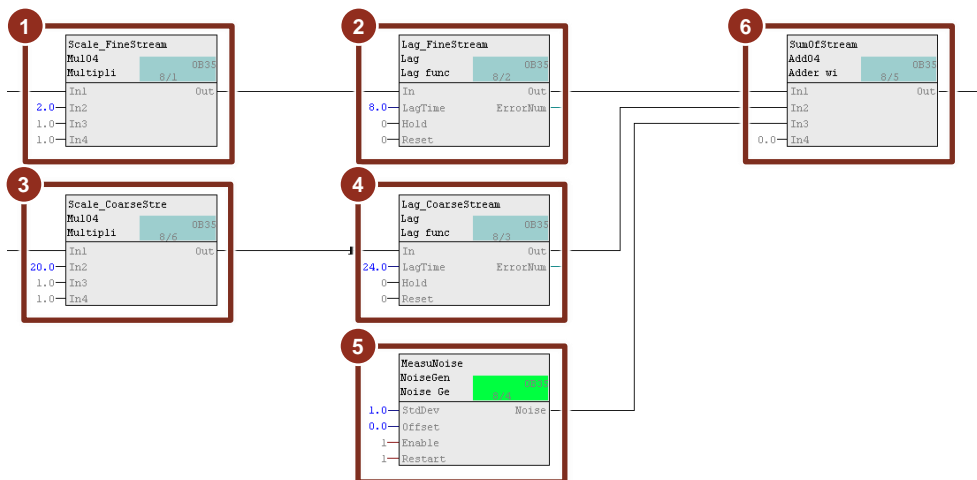
Control "FIC\_TotalStream" acquires the flow of the total stream and regulates the fine stream with control valve "YC\_FineStream".

The "FIC\_CoarseStream" controller acquires the manipulated value of the "YC\_FineStream" control valve and regulates the coarse flow with the "YC\_CoarseStream" control valve. The setpoint for the "FIC\_CoarseStream" controller is 50%. With it the "FIC\_CoarseStream" controller works to keep the "YC\_FineStream" control valve in the optimum working range of 50%.

**Structure and parameterization**

**"Sim\_Stream" simulation**

The flow of both the fine stream and the coarse stream are simulated in the "Sim\_Stream" CFC and the overall flow rate is calculated as well. Apart from this, the system displays the total flow rate based on process tag type "MonAn".



1. Calculation of the flow for the fine stream (valve 100 % open corresponds to inflow of 200 l/h)
2. Delay in change of flow (PT1 response with 8-second delay)
3. Calculation of the flow for the coarse stream (valve 100 % open corresponds to inflow of 2000 l/h)
4. Delay in change of flow (PT1 response with 24-second delay)
5. Determination of the complete flow quantity (addition)
6. Creation of measurement noise

**FIC\_TotalStream**

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	2200.0	Scaling of the process value upper limit
PV_Unit	In	1353	Unit of the process value l/h (liters per hour)
C	Gain.Value	5	Controller gain
C	Tl.Value	5	Controller lag
C	SP_InHiLim	2200.0	Maximum value of the internal setpoint
to_Actor_Slave	Out		Interconnection to the valve (YC_FineStream\from_Ctrl.In)
from_Actor_Slave	In		Interconnection to the valve (YC_FineStream\to_Ctrl.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\ Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_Stream\SumOfStream.Out)

**NOTE**

Procedure for controller tuning:

1. Take coarse stream controller in manual mode, go to typical operating point.
2. Optimized fine stream controller by PID-Tuner and take it to automatic mode.
3. Adjust deadband of fine stream controller with respect to measurement noise, such that the movements of the manipulated variable are sufficiently smooth.
4. Optimize coarse flow controller by PID-Tuner in manual mode, with a small step of manual value. The controlled process has negative gain: if the coarse flow controller opens its valve, the fine stream controller will compensate this by closing its valve. Process gain can be estimated from the ratio of maximal flows of both valves. Typical is a factor of about 10 between coarse flow and fine flow.
5. Specify the deadband of coarse flow controller with respect to the precision, that can be achieved realistically by the coarse flow controller, such that the coarse flow valve does not move at all in steady state operation.

**FIC\_CoarseStream**

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	100.0	Scaling of the process value upper limit
PV_Unit	In	1342	Process value unit %
C	NegGain	1	Negative gain of PID controller
C	Gain.Value	5	Controller gain
C	Tl.Value	24	Controller lag
C	DeadBand	10.0	Deadband
C	PV_In		Interconnection for the simulated process value (Sim_FineStream\I.MV)
to_Actor_Slave	Out		Interconnection to the valve (YC_CoarseStream\from_Ctrl.In)
from_Actor_Slave	In		Interconnection to the valve (YC_CoarseStream\to_Ctrl.Out)

**YC\_FineStream**

The instance has the following parameterization.

Block	Connection	Value	Use
V	MV		Interconnection for the simulation (Sim_Stream\Scale_FineStream.In1) Interconnection to the controller (YC_CoarseStream\C.PV)
from_Ctrl	In		Interconnection to the controller (FIC_TotalStream\to_Actor_Slave.Out)
to_Ctrl	Out		Interconnection to the controller (FIC_Totalstream\to_Actor_Slave.In)
MV_Out	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)

**YC\_CoarseStream**

The instance has the following parameterization.

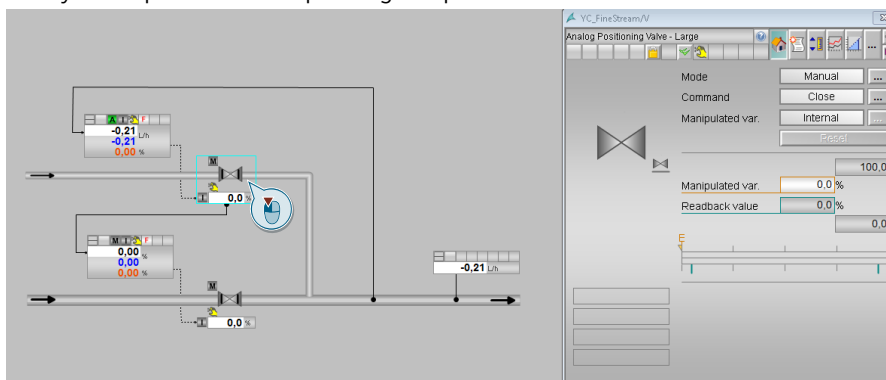
Block	Connection	Value	Use
V	MV		Interconnection for the simulation (Sim_Stream\Scale_CoarseStream.In1)
from_Ctrl	In		Interconnection to the controller (FIC_CoarseStream\to_Actor_Slave.Out)
to_Ctrl	Out		Interconnection to the controller (FIC_Coarsestream\to_Actor_Slave.In)
MV_Out	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)

## Commissioning and operation

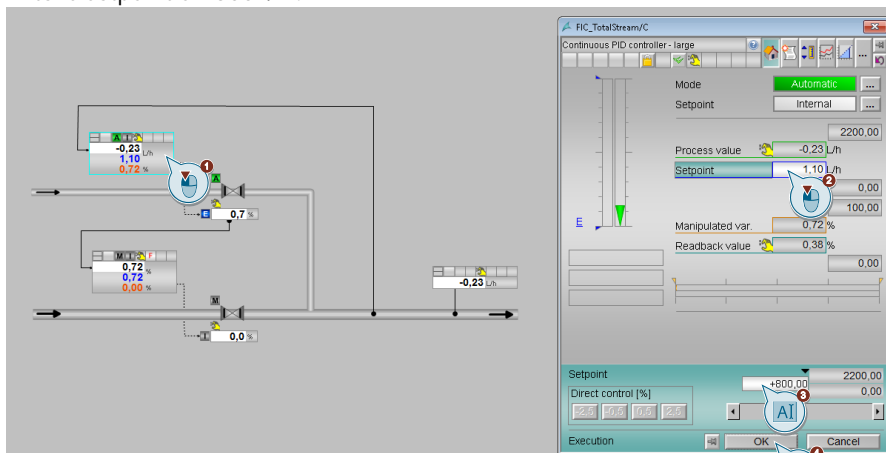
For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

Proceed as follows:

1. Click on the symbol display of the "YC\_FineStream" valve.  
The system opens the corresponding faceplate.



2. In the faceplate, change the operating mode to "Automatic".
3. Switch to controller "FIC\_TotalStream" and change the controller's operating mode to "Automatic".
4. Enter a setpoint of "800 l/h".



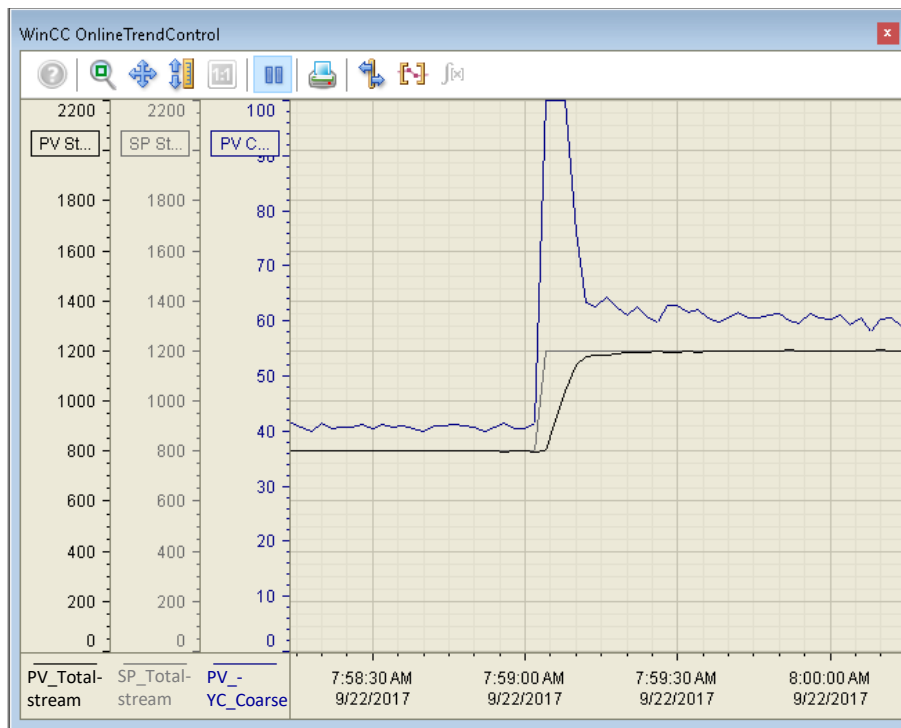
5. Switch to "YC\_CoarseStream" valve and change the operating mode to "Automatic".
6. Switch to "FIC\_CoarseStream" valve and change the operating mode to "Automatic" and the setpoint to "External".

### NOTE

The controller uses the preset setpoint "50" % as external setpoint to keep the valve "YC\_FineStream" in the middle of the working range.

7. Then wait about 1 minute until both controllers have reached their setpoints and change the main controller setpoint to "1200 l/h".
8. Wait for about 30 seconds and then click on the "Start/Stop" icon on the toolbar of the OnlineTrendControl.

## Evaluation



The setpoint step from 800 l/h to 1200 l/h opens the valve for the fine stream completely. The coarse stream controller registers the change of the fine stream control valve and regulates the coarse stream valve accordingly. This leads to a significant change of the total flow so that the controller for the total flow closes the fine stream valve again until the total flow has reached the new setpoint value.

**NOTE**

Typical a large disturbance moves the overall flow away from its setpoint. The fine stream controller is supposed to react quickly and compensate the disturbance, but will reach one of its manipulated variable limits. The coarse flow controller slowly adapts to the situation and allows the fine stream controller to return to the center of its manipulated variable range.

## 5.9. Gradient limits in actuators

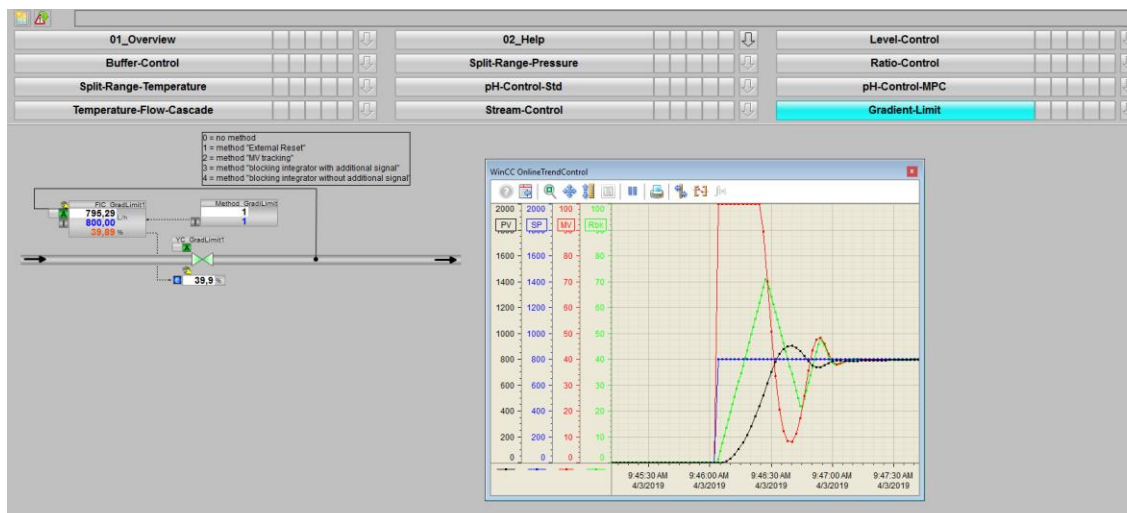
### "Gradient-Limit"

Numerous mechanical actuators in process plants, such as control valves, pumps with variable speed or thermostatic baths, react only with limited speed to a change in the manipulated variable. As a result, the valve position, the pump speed or the bath temperature cannot be changed as quickly as required and the achievable gradient of the controller's manipulated variables is limited. Even with a linear controller and an otherwise linear system, the behavior of the closed control loop in this case is not independent of the amplitude, it depends on the signal form of the manipulated variable.

There is no effect of gradient limitation for slow manipulated variable changes. The steeper the signal edge, the stronger the delaying effect. This alters the visible dynamics of the controlled system from the controller's point of view. Since the behavior is not known to the controller, integrator windup may occur in PID controllers leading to strong overshoots.

If the speed of the actuator is sufficiently fast compared to the other time constants of the controlled system, the control dynamics are hardly distorted. If the dynamics are more strongly distorted, the controller is usually designed according to the worst-case scenario, i.e. according to the largest occurring setpoint steps. In all other scenarios, such as disturbance behavior, significant limitations of control performance are imposed.

In the following, the problem is presented using a simple flow control loop, consisting of PID controller and valve, and four methods for improving control dynamics are explained.

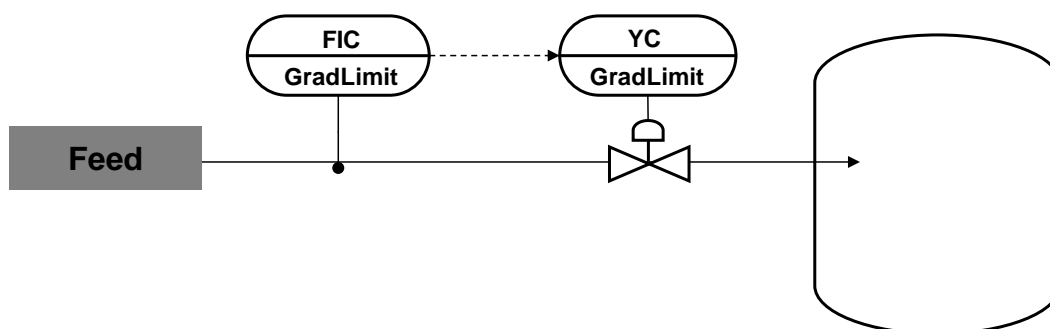


#### Overview

Below, the structure in the P&ID is shown and all CMs and the simulation of the equipment module are described. The structure is described in general for all methods. The modifications of the respective method are explained in the corresponding subchapter.

#### P&I Diagram

The P&ID below symbolically represents all of the components, such as field devices and containers relevant to operation.



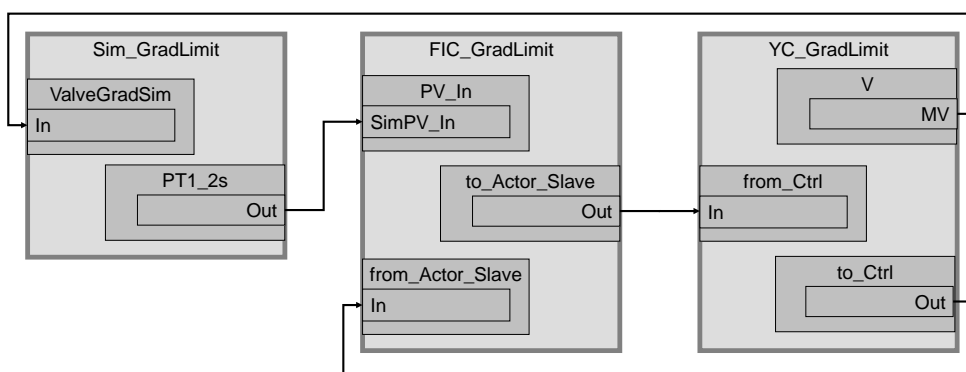
**CM and variants**

The technical function "GradientLimit" consists of two interconnected CMs and a simulation plan. The behavior of the controlled system is simulated in the simulation plan.

The following table provides an overview of the CMs of the equipment module, including the associated CMTs.

CM	CMT	Variant	Description
FIC_GradLimit	PIDCon	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale#</li> </ul>	Flow controller
YC_GradLimit	VlvAn	<ul style="list-style-type: none"> <li>IF_Ctrl#</li> <li>MV_Scale#</li> <li>RbkReturn</li> <li>YC</li> </ul>	Control valve

In the figure below, the structure with the cross-chart interconnections is shown in simplified form.

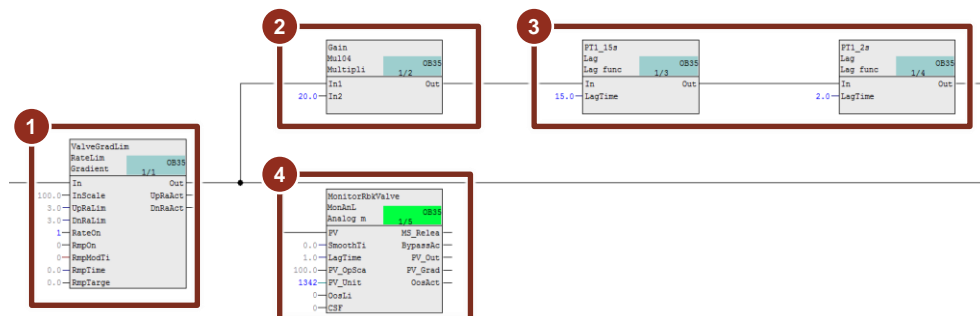


The "FIC\_GradLimit" controller detects the flow and controls it using the "YC\_GradLimit" control valve. In the CFC chart "SimGradLimit", the flow rate is calculated from the control value for the valve and the gradient limitation.

**Structure and parameterization**

**Simulation "Sim\_GradLimit"**

The CFC "Sim\_GradLimit" simulates the gradient limitation of the control valve and the flow rate.



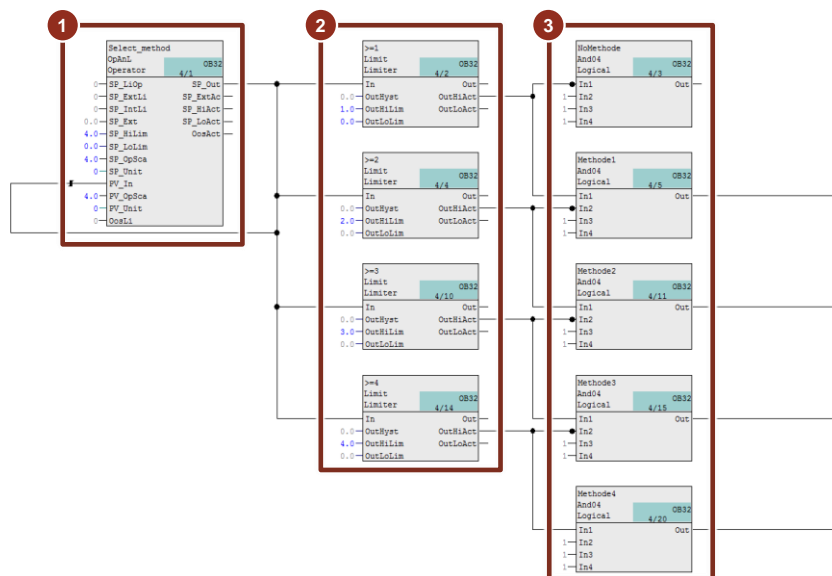
1. Calculation of the valve feedback (valve position in the range 0...100 % and a maximum travel speed of 3 %/s in both directions)
2. Calculation of the flow rate (100 % valve opening corresponds to an inlet of 2000 l/h)
3. Flow change delay (PT2 behavior with 15 seconds and 2 seconds delay)
4. Visualization of the position feedback in the WinCC Runtime

**CFC "Method\_GradLimit"**

In the CFC "Method\_GradLimit" the different methods for considering the gradient limitation of the actuator are selected and activated.

The respective methods are activated in sub-sheets 1 to 4, the description of the individual methods can be found in the following sub-sheets. The methods are selected in Subsheet 6.





1. Selection of the method from WinCC Runtime
2. Checking the input
3. Activation of the respective method for consideration of gradient limitation

### FIC\_GradLimit

The instance has the following parameterization.

Block	Connection	Value	Use
PV_Scale	HiScale	2000.0	Scaling of the process value upper limit
PV_Unit	In	1353	Unit of the process value l/h (liters per hour)
C	Gain.Value	5	Controller gain
C	Tl.Value	28	Controller lag
C	SP_InHiLim	2000.0	Maximum value of the internal setpoint
to_Actor_Slave	Out		Connection to valve (YC_GradLimit\from_Ctrl.In)
from_Actor_Slave	In		Interconnection for the valve (YC_GradLimit\to_Ctrl.Out)
PV	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)
PV	SimPV_In		Interconnection for the simulated process value (Sim_GradLimit\PT1_2s.Out)

### YC\_GradLimit

The instance has the following parameterization.

Block	Connection	Value	Use
V	MV		Interconnection for the simulation (Sim_GradLimit\ValveGradLim.In)
from_Ctrl	In		Interconnection for the controller (FIC_GradLimit\to_Actor_Slave.Out)
to_Ctrl	Out		Interconnection for the controller (FIC_GradLimit\to_Actor_Slave.In)
YC	SimOn		Activation of simulation on the channel block (Equipment_Modules\Activate_Simulation\Sim_Act.Out)

## 5.9.1. Control behavior without active method

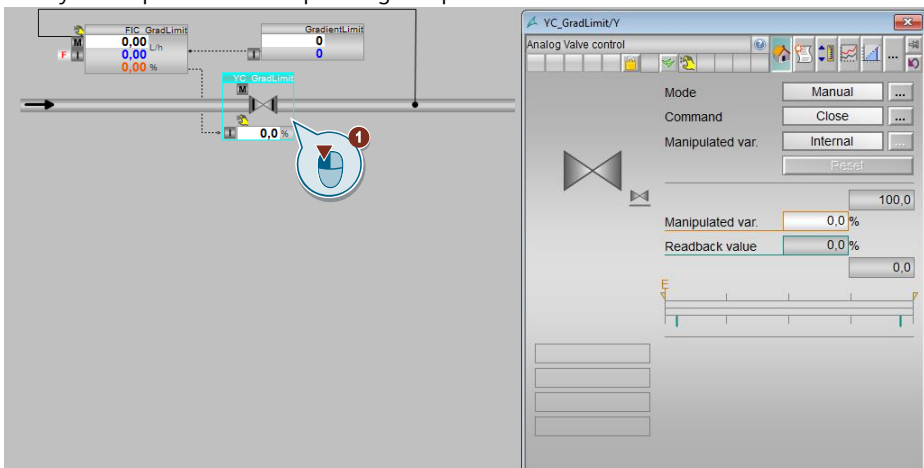
### Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

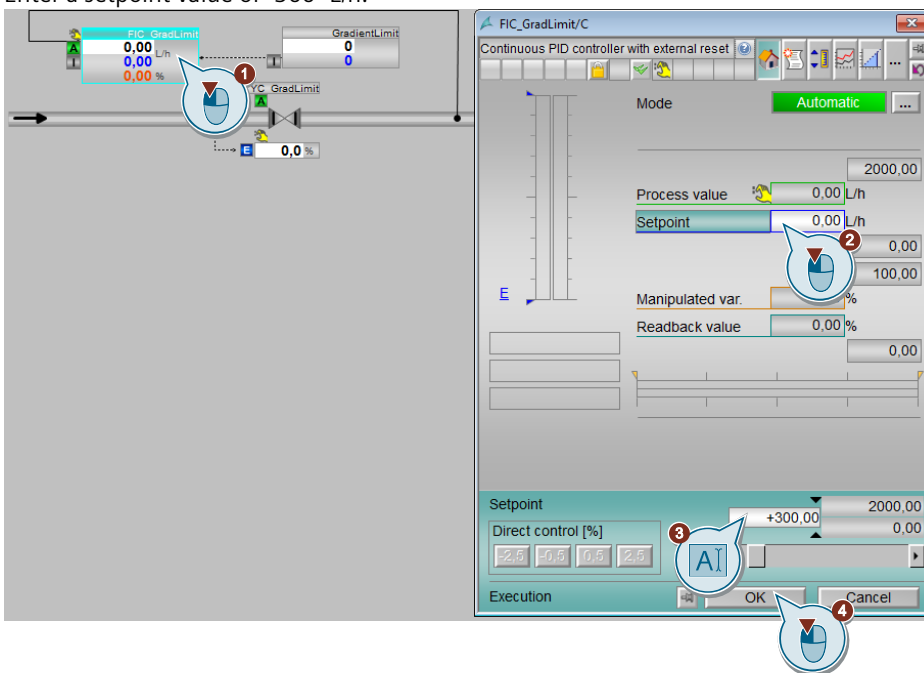
Proceed as follows:

1. Click on the block symbol of the valve "YC\_GradLimit1".

The system opens the corresponding faceplate.



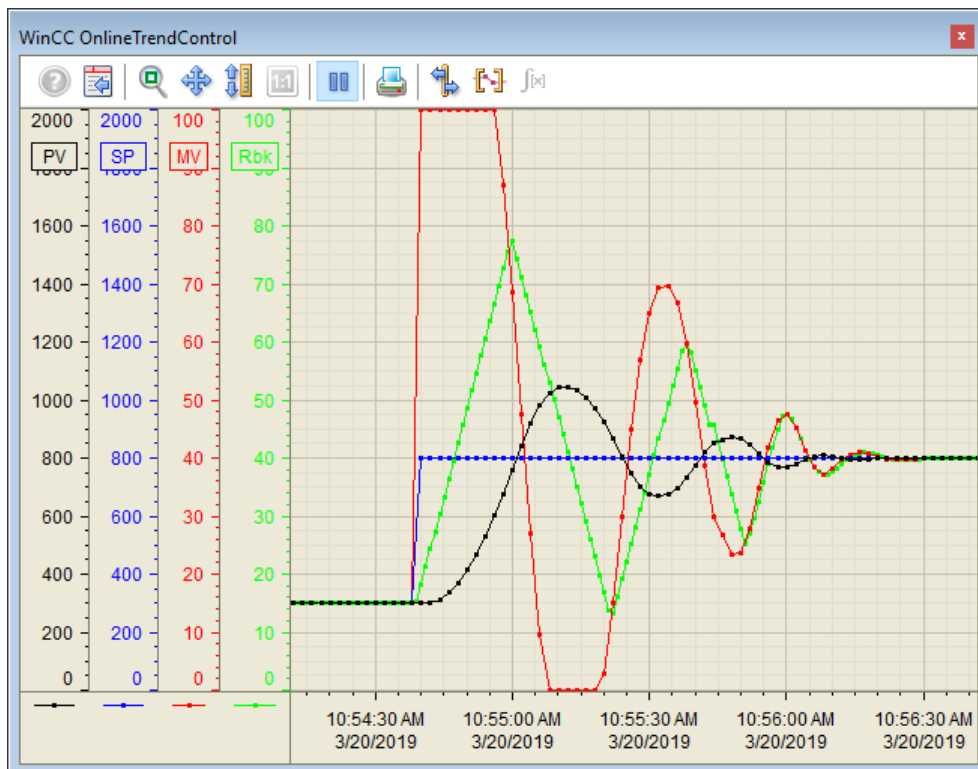
2. In the faceplate, change the operating mode to "Automatic".
3. Switch to the controller "FIC\_GradLimit1" and change the operating mode of the controller to "Automatic".
4. Enter a setpoint value of "300" L/h.



The new setpoint will be reached after approximately two minutes.

5. Specify a new setpoint of "800" L/h for the controller.
6. Close the faceplate and observe the trend curve for about two minutes until the new setpoint has been reached.

## Evaluation



During the positive setpoint step, a significant difference between the manipulated variable for the valve and the actual valve position (position readback signal, green) is visible. The actual valve position cannot follow the commands of the controller (red) fast enough due to the gradient limitation. Since the difference between the manipulated variable for the valve and the actual valve position is not known to the controller, an overshoot of more than 30 % of the step height occurs, which would not be acceptable in many applications.

## 5.9.2. Method 1 "External Reset"

For controllers with an incremental algorithm that have an input variable for external reset, setting the manipulated variable from the last sampling step (e.g. PIDConR.ExtReset), the actual actuator position is connected to this reset input. This prevents the controller manipulated variable from drifting too far away from the position feedback signal.

### Setup

#### NOTE

Instead of the PIDConL controller, method 1 "External Reset" uses the PIDConR controller from the Advanced Process Library.

The following parameterization is required for the "External reset" method:

Block	Connection	Value	Use
C	ExtRstOn	1	Activate external reset

The following wiring is used in addition to the standard wiring:

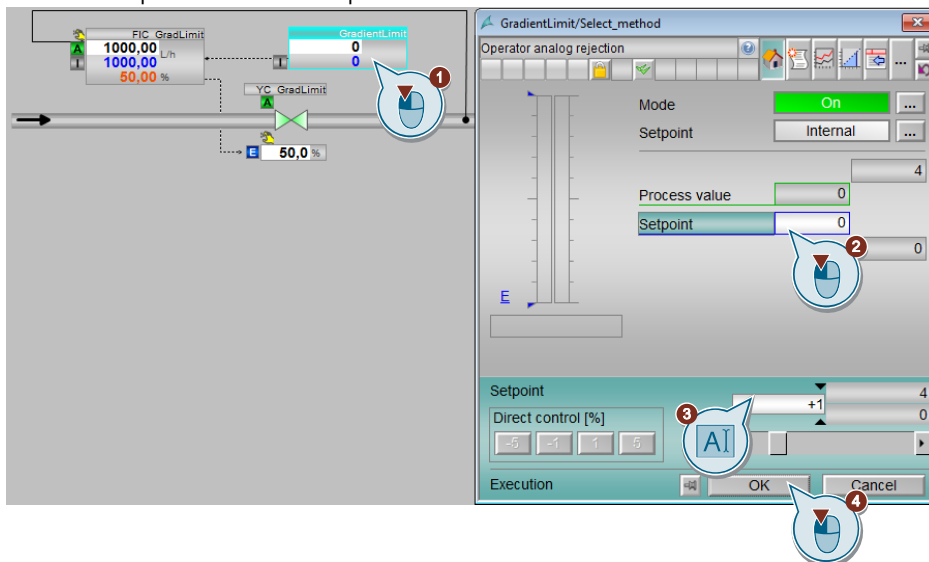
Block	Connection	Target	Description
C	ExtReset	Circuit for position feedback of the valve	Reset value for ExtRstOn = 1

### Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

Proceed as follows:

1. Enter the setpoint "1" at the faceplate "GradientLimit".

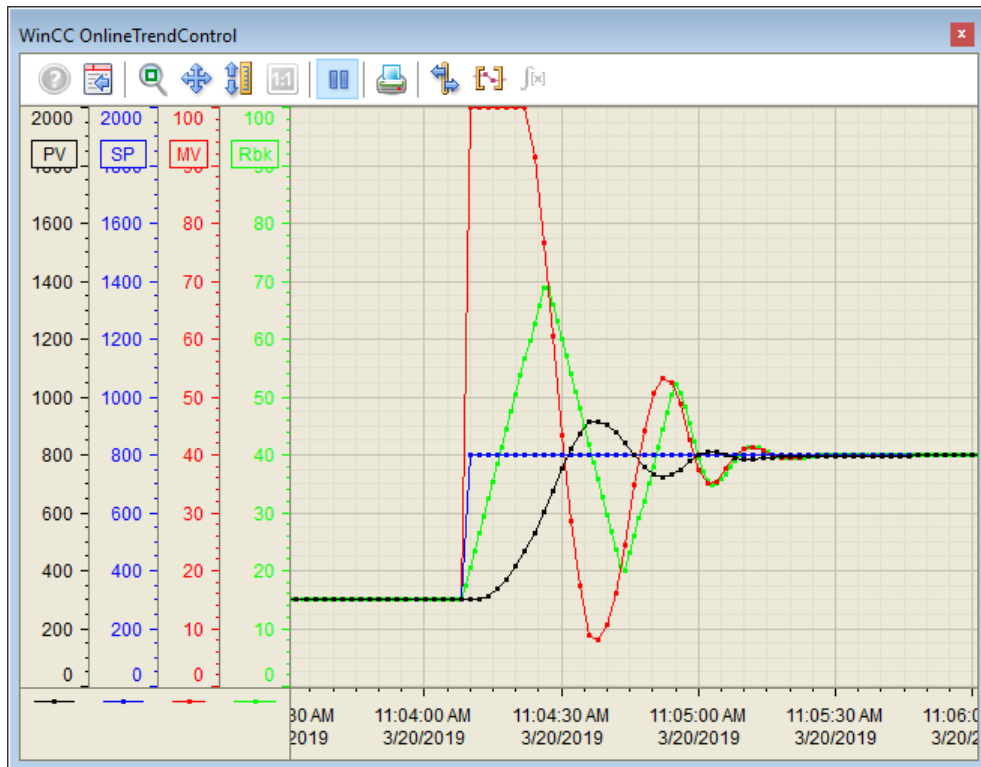


2. In the "YC\_GradLimit1" valve faceplate, change the operating mode to "Automatic".
3. Switch to the controller "FIC\_GradLimit1" and change the operating mode to "Automatic".
4. Also enter a setpoint of "300" L/h in the controller's faceplate.

The new setpoint will be reached after approximately two minutes.

5. Specify a new setpoint of "800" L/h for the controller.
6. Close the faceplate and observe the trend window for about two minutes until the new setpoint has been reached.

## Evaluation



With the "External reset" method activated, a significantly better control response is achieved for the same setpoint step, the overshoot is significantly smaller, and the settling time is also shorter.

## 5.9.3. Method 2 "Tracking output value in case of excessive deviation"

With the method "Tracking output value in case of excessive deviation", the controller output is adjusted to the current position feedback signal as soon as the difference between the controller output and the position feedback signal exceeds a limit (e.g. 25 % of the positioning range).

### Setup

Three additional blocks ("Sub02", "AbsR" and "CompAn02") from the Advanced Process Library are required for the method "Adjust control value if deviation is too large".

The following parameterization is required:

Block	Connection	Value	Use
CompAn02	In2	25	Difference between output value and position feedback signal at which the output value is to be reset

The following wiring is used in addition to the standard wiring:

Block	Connection	Target	Description
Sub02	In1	Connection to the manipulated variable of the valve	Form difference between manipulated variable and position feedback signal
Sub02	In2	Circuit for position feedback of the valve	
Sub02	Out	AbsR.In	Output of the difference between manipulated variable and position feedback signal
AbsR	In	Sub02.Out	Form absolute value
AbsR	Out	CompAn02.In1	Output of the absolute difference
CompAn02	In1	AbsR.Out	Compare difference independent of direction
CompAn02	GT	C.MV_TrkOn	If the difference between the output value and the position feedback signal is large, adjust the output value of the controller.
C	MV_TrkOn	CompAn02.GT	Activating the output value
C	MV_Trk	Circuit for position feedback of the valve	Tracking value for manipulated variable MV

### Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

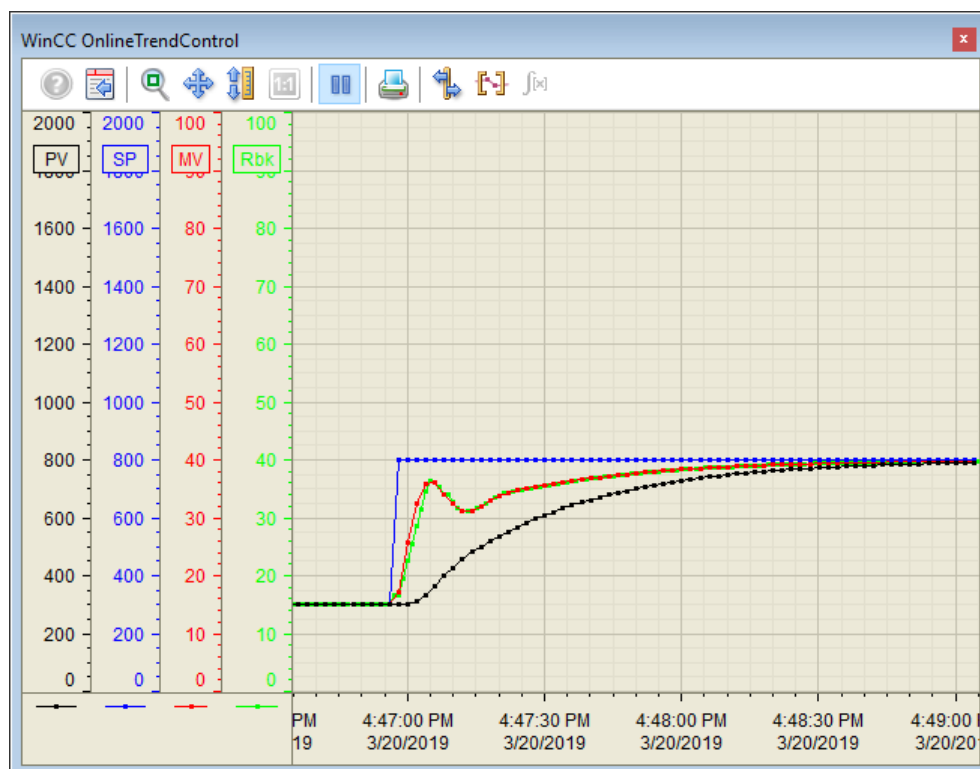
Proceed as follows:

1. Enter the setpoint "2" at the faceplate "GradientLimit".
2. In the "YC\_GradLimit2" valve faceplate, change the operating mode to "Automatic".
3. Switch to the controller "FIC\_GradLimit2" and change the operating mode to "Automatic".
4. Also enter a setpoint of "300" L/h in the controller's faceplate.

The new setpoint will be reached after approximately two minutes.

5. Specify a new setpoint of "800" L/h for the controller.
6. Close the faceplate and observe the trend window for about two minutes until the new setpoint has been reached.

## Evaluation



After the difference between the manipulated variable and the position feedback signal exceeds the parameterized limit value, the controller output (red) is set to the position feedback signal (green). This limits the manipulated variable curve and completely avoids overshoot. The method is not effective for smaller setpoint steps because the difference between the controller output and the position feedback signal does not exceed the limit value.

### 5.9.4. Method 3 "Blocking integrator"

Another method of handling actuator gradient limitation is the method of blocking the integrator. For this purpose, signals showing if manipulated variable limits are reached, are read from the underlying valve positioner (e.g. Sipart PS) in order to block the integrator in a direction-dependent manner. This method acts very specifically against integrator windup and corresponds to what is proposed for cascade control within the distributed control system (interconnection of the function blocks for master and slave controllers, see templates of the PCS 7 Advanced Process Library). This assumes that binary feedback signals from the actuator are available as soon as the actuator reaches its internal manipulated variable limitation and the gradient limitation thus takes effect.

Setup

The following wiring is used in addition to the standard wiring:

Block	Connection	Target	Description
C	IntHoldPos	Limitation of the manipulated variable in positive traverse direction from the downstream valve positioner	Block integrator in positive direction
C	IntHoldNeg	Limitation of the manipulated variable in negative traverse direction from the lower-level valve positioner	Block integrator in negative direction

## Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

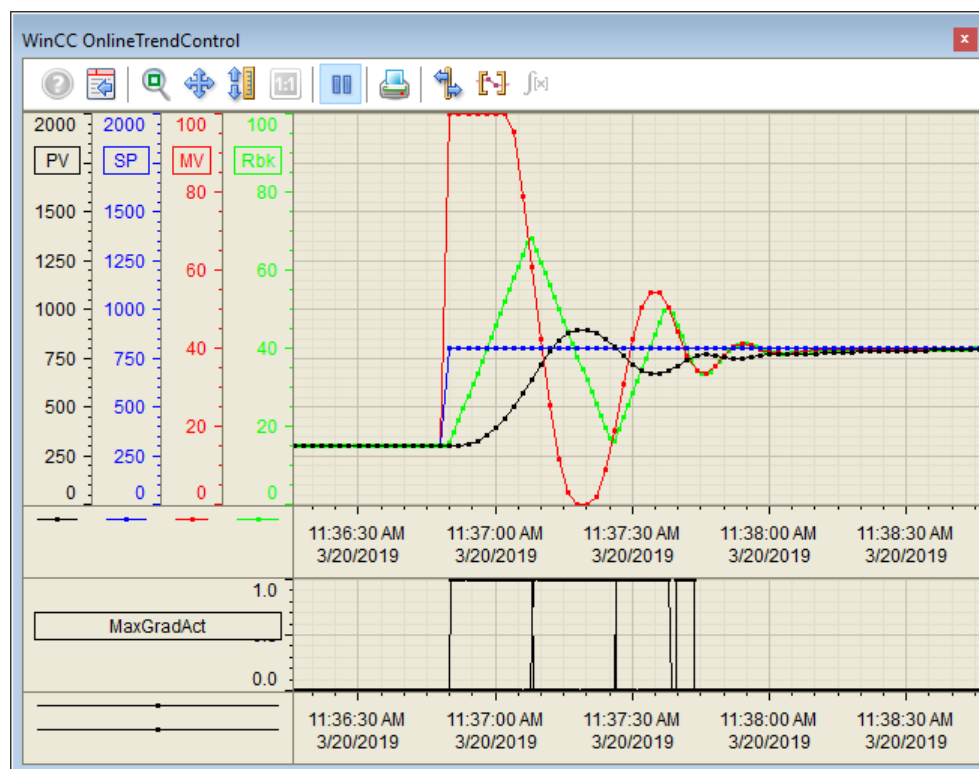
Proceed as follows:

1. Enter the setpoint "3" at the faceplate "GradientLimit".
2. In the "YC\_GradLimit3" valve faceplate, change the operating mode to "Automatic".
3. Switch to the controller "FIC\_GradLimit3" and change the operating mode to "Automatic".
4. Also enter a setpoint of "300" L/h in the controller's faceplate.

The new setpoint will be reached after approximately two minutes.

5. Specify a new setpoint of "800" L/h for the controller.
6. Close the faceplate and observe the trend window for about two minutes until the new setpoint has been reached.

## Evaluation



With the "Blocking integrator" method activated, the integrator windup can be suppressed such that the overshoot is reduced during the setpoint step. The lower part of the trend shows when the gradient limitation is active.

Direction-dependent blocking has the advantage that it works independently of the step height, such that tracking behavior is less slowed down, and no parameterization is required. However, the binary signals required for this are only available for a few installations in the distributed control system.

One example is an electro-pneumatic valve positioner, which often operates internally as a 5-point positioner. The so-called slow gear zone, in which an approximately proportional control behavior is visible, covers only 1...10 % of the valve position range. As soon as the control deviation leaves this range, the positioner opens the maximum air supply to the valve actuator, i.e. it operates at its manipulated variable limit. This happens frequently during operation with large setpoint steps. The corresponding binary signals are usually only available for internal use within the field device and are not made available to the outside world via a communication interface.



## 5.9.5. Method 4 "Blocking integrator with gradient calculation"

The "Blocking integrator with gradient calculation" method allows directional blocking of the integrator even in cases where no feedback can be received from the actuator showing that the actuator is moving at maximum speed. For this purpose, this information is reconstructed inside the process control system by calculating the current gradient of the valve position and comparing it to the known limit value of the maximum travel speed.

Typically position feedback is superimposed by measuring noise, therefore a low-pass filtering with meaningful time constant must be performed in front of the differentiator.

### Setup

For the "Blocking integrator with gradient calculation" method, three additional blocks ("Derivative" and twice "CompAn02") from the Advanced Process Library are required.

The following parameterization is required:

Block	Connection	Value	Use
Derivative	OutHiLim	-100.0	Maximum gradient in negative direction
Derivative	LagTime	1.0	Low pass delay time
CompAn02_pos	In2	2.9	Comparison gradient in positive direction
CompAn02_neg	In2	-2.9	Maximum gradient in negative direction

The maximum gradient must be parameterized so that it is just below the real gradient limit. Otherwise the limitation would not be detected.

The following wiring is used in addition to the standard wiring:

Block	Connection	Target	Description
Derivative	In	Connection to the manipulated variable of the valve	Calculation of the travel gradient
Derivative	Out	CompAn02_pos.In CompAn02_neg.In	Output of the calculation of the travel gradient
CompAn02_pos	In1	Derivative.Out	Comparison of maximum travel speed in positive direction
CompAn02_pos	Out	C.IntHoldPos	Maximum travel speed reached in positive direction
CompAn02_neg	In1	Derivative.Out	Comparison of maximum travel speed in negative direction
CompAn02_neg	Out	C.IntHoldPos	Maximum travel speed reached in negative direction
C	IntHoldPos	CompAn02_pos.Out	Block integrator in positive direction
C	IntHoldNeg	CompAn02_neg.Out	Block integrator in negative direction

## Commissioning and operation

For commissioning and operation, it is assumed that the user program has been loaded in the automation system (AS) or the S7-PLCSIM and that the OS (WinCC Runtime) has been activated. You can find a guide for loading the user program and activating the OS in chapter 2 "[Preparation and commissioning](#)".

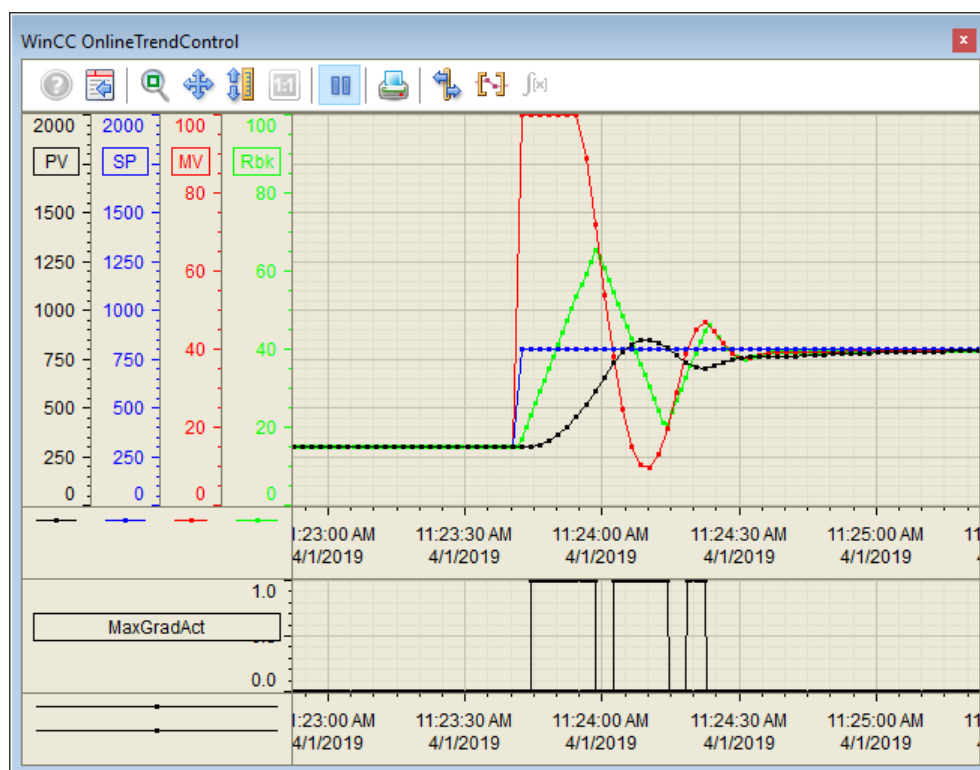
Proceed as follows:

1. Enter the setpoint "4" at the faceplate "GradientLimit".
2. In the "YC\_GradLimit4" valve faceplate, change the operating mode to "Automatic".
3. Switch to the controller "FIC\_GradLimit4" and change the operating mode to "Automatic".
4. Also enter a setpoint of "300" L/h in the controller's faceplate.

The new setpoint will be reached after approximately two minutes.

5. Specify a new setpoint of "800" L/h for the controller.
6. Close the faceplate and observe the trend window for about two minutes until the new setpoint has been reached.

## Evaluation



With the activated method "Blocking integrator with gradient calculation", the integrator windup can also be suppressed such that the overshoot is reduced during the setpoint step. Due to the delay caused by the low-pass filter, the effect of the method is not quite as good as if the original binary signals are available.

## 5.9.6. Methods comparison

In control loops with mechanical actuators whose moving speed is so strongly limited that the delaying effect of the gradient limitation cannot be neglected compared to the other time constants of the controlled system, a windup of the integrator can be avoided by applying one of the four methods. This allows to reduce the overshoot, especially with large setpoint steps, without generally tuning the controller very sluggish and thus also impairing the disturbance compensation of the control loop.

The following table compares the methods for suppressing integrator windup in case of gradient limitations of the manipulated variable.

Method	Requirements	Parameters	Effect
External reset	Controller block PIDConR  Analog position feedback from actuator	None	reduces divergence of setpoint and feedback of the actuator in case of large setpoint steps, reduces overshoot
Tracking output value in case of excessive deviation	Analog position feedback	Switching threshold for maximum deviation e.g. 25 %.	Proportional step is truncated, tracking behavior is slowed down, slow settling times
Blocking integrator	Controller block PIDConL binary feedback from actuator when internal manipulated variable limitation is active (i.e. gradient is limited)	None	Avoids windup in case of active gradient limitation, reduces overshoots
Integrator blocking with gradient calculation	Controller block PIDConL Analog position feedback from actuator	maximum travel gradient  Low pass filtering with meaningful time constant	Avoids windup in case of active gradient limitation, reduces overshoots

The "External Reset" method has the advantage that it can be used for controllers with incremental algorithms without further parameterization and without special requirements on the feedback signals from the final control element.

The method "Tracking the output value in case of excessive deviation" has the widest range of application. It does not require a special control algorithm, binary feedback signals or high signal quality of the analog feedback signal. Only application-specific limit values must be parameterized. The method slows down the tracking behavior for large setpoint steps and remains completely ineffective for small setpoint steps.

The "Blocking integrator" method achieves the highest overall control performance for setpoint steps of different heights, but requires binary feedback signals from the actuator when its internal manipulated variable signal limitation is active.

The "Blocking Integrator with gradient calculation" method allows the use of directional integrator blocking with reduced precision even when there are no binary feedback signals from the actuator. For this the maximum actuator gradient and a meaningful filter time constant must be determined.

### Selecting the method

When selecting the method for considering gradient limits in final control elements, the following sequence of criteria can be used:

1. If an incremental control algorithm is used, the "External Reset" method is preferred.
2. If no incremental control algorithm is used, but the binary feedback signals of the actuator are available when the internal manipulated variable limitation is active, the "Blocking integrator" method should be selected.
3. If the binary feedback signals are not available, the method "Blocking integrator with gradient calculation" must be selected as an alternative.
4. If sufficient smoothing of the position readback signal is not possible or the filter time constant is not negligible small compared to the time constants of the controlled system, use the method "Tracking output value in case of excessive deviation".

## 5.10. Instance-specific adaptations

**NOTE** No alarm, warning or tolerance limits are pre-parameterized in the equipment modules. If you parameterize a limit value, you must also activate the corresponding notification.  
For example, parameter "PV\_AH\_En" for upper alarm limit "PV\_AH\_Lim".

**NOTE** Interconnection of the process variables depends on the selected variant of a CM. In the configuration below, the control, process, and manipulated variables are acquired via the "Pcs7AnIn" and "Pcs7AnOu" analog channel blocks.

The tables below contain the relevant parameters that you must either set or interconnect.

### Controller

Block	Connection	Use
C	Gain	Proportional gain
C	TD	Differential action time in s
C	TI	Integral action time in [s]
C	SP_InHiLim	(Upper) limit value of the internal setpoint
C	SP_InLoLim	Limit (lower) of internal setpoint
C	PV_AH_En	Alarm in case of upper limit value violation if $PV \geq PV\_AH\_Lim$
C	PV_WH_En	Alarm in case of upper limit value violation if $PV \geq PV\_WH\_Lim$
C	PV_TH_En	Tolerance in case of upper limit value violation if $PV \geq PV\_TH\_Lim$
C	PV_TL_En	Tolerance in case of lower limit value violation if $PV \leq PV\_TL\_Lim$
C	PV_WL_En	Alarm in case of lower limit value violation if $PV \leq PV\_WL\_Lim$
C	PV_AL_En	Alarm in case of lower limit value violation if $PV \leq PV\_AL\_Lim$
C	ER_AH_En (hidden)	Alarm in case of upper control difference violation if $ER \geq ER\_AH\_Lim$
C	ER_AL_En (hidden)	Alarm in case of lower control difference violation if $ER \leq ER\_AL\_Lim$
PV_Scale	HiScale LoScale	Scaling of the measured value (e.g. maximum container fill level of 10000)
PV_Unit	IN	Unit of the scaled measured value (e.g. 1038 fill level in liters)
PV	PV_In	Acquisition of the controlled variable, e.g. fill level

### Display

Block	Connection	Use
I	PV_AH_En	Alarm in case of upper limit value violation if $PV \geq PV\_AH\_Lim$
I	PV_WH_En	Alarm in case of upper limit value violation if $PV \geq PV\_WH\_Lim$
I	PV_TH_En	Tolerance in case of upper limit value violation if $PV \geq PV\_TH\_Lim$
I	PV_TL_En	Tolerance in case of lower limit value violation if $PV \leq PV\_TL\_Lim$

Block	Connection	Use
I	PV_WL_En	Alarm in case of lower limit value violation if $PV \leq PV\_WL\_Lim$
I	PV_AL_En	Alarm in case of lower limit value violation if $PV \leq PV\_AL\_Lim$
PV_Scale	HiScale LoScale	Scaling of the measured value (e.g. maximum container fill level of 10000)
PV_Unit	IN	Unit of the scaled measured value (e.g. 1038 fill level in liters)
PV	PV_In	Acquisition of the process variable, e.g. fill level

**Valve**

Block	Connection	Use
V	MV_HiLim MV_LoLim	Upper and lower limit of the manipulated value
MV_Scale	HiScale LoScale	Scaling of the manipulated variable (manipulated value of the valve block)
MV_Unit	IN	Unit of the scaled manipulated variable
MV_Out	PV_Out or PV_ChnST	Channel blocks for linking a control valve Output of the manipulated variable or Output of the manipulated variable including the signal status

**NOTE**

In the object properties of the message-type blocks, you can configure instance-specific messages. You can find a guide to the procedure in the "SIMATIC PCS 7 Process Control System; Operator Station (V9.1)" configuration manual under <https://support.industry.siemens.com/cs/ww/de/view/109794374>.

# 6. Additional information

## 6.1. General Information

### Automation technology

Industrial processes in the chemicals or pharmaceuticals sectors, for example, are controlled and regulated using automation technology.

The degree of automation of systems varies considerably and depends on the system type and the process.

In general, an automation solution includes the following aspects:

- Measurement and control
- Possibly, control of higher quality control strategies
- Transferring, processing and representing information
- Complying with defined steps and procedures
- Observing complex contexts
- Guaranteeing constant product quality
- Strategies in the case of deviations from or exceeding of process parameters or of component failures

### Process control

The operator's main task is to carry out operative process control based on process and plant information with respect to production process and its logistics and auxiliary processes.

The task of process control is to guarantee that operating conditions are kept in, compliance with defined tolerance ranges for process safety and product quality, in a selective and reproducible way. In case of disturbances, the process has to be driven back to the desired operating state. In addition, the production sequence should be continuously optimized regarding costs, quality, and safety.

Using SIMATIC PCS 7 Advanced Process Graphics (APG), it is possible to make process visualization more efficient for operators. When doing this, the system shows the information in the plant overview that is relevant for orientation and navigation. The information that is necessary for operator control and monitoring of a plant unit, e.g. a reactor, is made available in a lower-level process picture. This procedure provides the great advantage of dispensing information in a task-oriented way that is optimized for process operation.

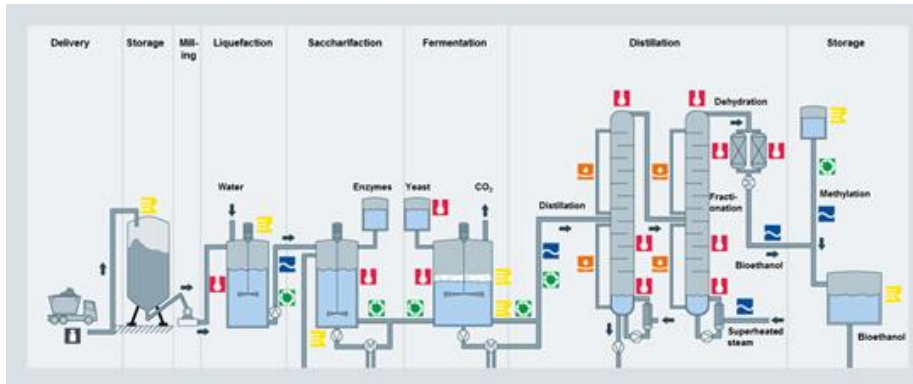
#### NOTE

You can find detailed information and the procedure for configuring APG in the Siemens Industry Online Support in the entry entitled "Integration of Advanced Process Graphics in SIMATIC PCS 7" under <https://support.industry.siemens.com/cs/ww/en/view/89332241>.

## 6.2. Standardized plant units

### Partial automation solution

The figure below shows the components of an automation solution for a process plant. The production process is divided into several steps, e.g. fermentation and distillation. In this connection, one process step corresponds to one plant unit, which, for its part, can consist of different equipment modules, e.g. addition of starting material or agitation.



### Unit

The term plant unit represents an apparatus (device) in process plants (e.g. stirred tank reactor, fermenter) which includes sensor technology, actuators and automation (hardware and software).

There are structured units for both continuous and discontinuous processes.

Package units are variants of a plant units. Examples of package units include refrigeration systems, vacuum systems and packaging machines. In this case, the manufacturer of the mechanical or technical device includes automation technology, specially tailored for this device, which is mounted locally on the device on a separate hardware platform. The package unit is integrated as a whole into a higher-level process control system.

### Equipment module

An equipment module forms part of a unit and contains sensors, actuators and the automation system (hardware and software). Equipment modules are designed and configured for use in concrete applications, such as process technology (dosing device, level or temperature control).

The automation solution of an equipment module is structured as follows:

- Connected and parameterized process tags
- Elementary simulation to demonstrate the mode of operation for virtual commissioning, not necessary for plant operation

Each equipment module is combined in a hierarchy folder and can be integrated into existing projects.

### Control module

Actuators and sensors are used at the control module level as control modules.

In PCS 7, the control module is implemented with software typicals (control module types) such as a valve, motor, or controller, for example.

The implementation in the CFC contains all the relevant building blocks, interconnections, and basic parameters. A control module type is produced from the CFC, which is then stored in the PCS 7 master data library. You can create as many instances as you like from this control module type using the Automation Interface, for example. There can be major differences between the instances, e.g. you can select options for functions as well as for the process link.

Each designation of a control module follows a uniform naming convention. This means that the name provides information about the function and the job of the control module.

## Unit Template

A Unit Template is composed of several equipment modules. In a Unit Template, equipment modules are grouped into a partial automation solution.

In addition, it is possible to display other information in a Unit Template, such as economic or process engineering parameters (KPIs) or the operating times of equipment.

A Unit Template is grouped in a hierarchy folder and you can easily integrate it into existing projects and adapt it.

In contrast to package units, no local isolated control systems with their own hardware are set up; rather, in the Unit Template concept, pre-assembled software solutions are created in a central process control system for frequently occurring unit types. Partial automation solutions for process plants are provided on a uniform pre-assembled basis and can be edited by users. This means that it is sufficient to adapt the templates to the existing process plant and automation hardware. This significantly reduces the engineering effort required for several similar automation tasks.

## Configuration with templates

You can carry out configuration using templates at the equipment module or control module level.

At the control module level, you use control module types in PCS 7 to create a template for creating instances. It is possible to compare and match the instances of the control module types with the PCS 7 Automation Interface.

Equipment modules or plant units are duplicated as a unit and adapted to the corresponding process engineering.

The equipment modules and the Unit Template contain all functions that are needed for automation in form of:

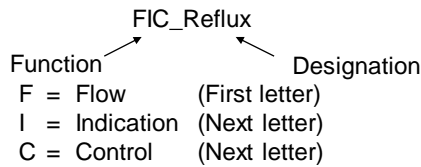
- CFCs (instances of control module types)
- SFCs
- OS pictures



## 6.3. Design and structure

### 6.3.1. CFC naming convention

A uniform naming convention was used to identify the control modules with the function being named according to European standard EN 62424 or to ISO 3511. The figure below shows how a label is composed:



The table below contains all the letters that are used in the Application Example and their meanings:

First letter	Meaning
F	Flow
J	Power
L	Level
M	Moisture
N	Motor
P	Pressure
Q	Amount, quantity or quality
S	Speed
T	Temperature
W	Weight
X	Freely selectable first letter
Y	Control valve

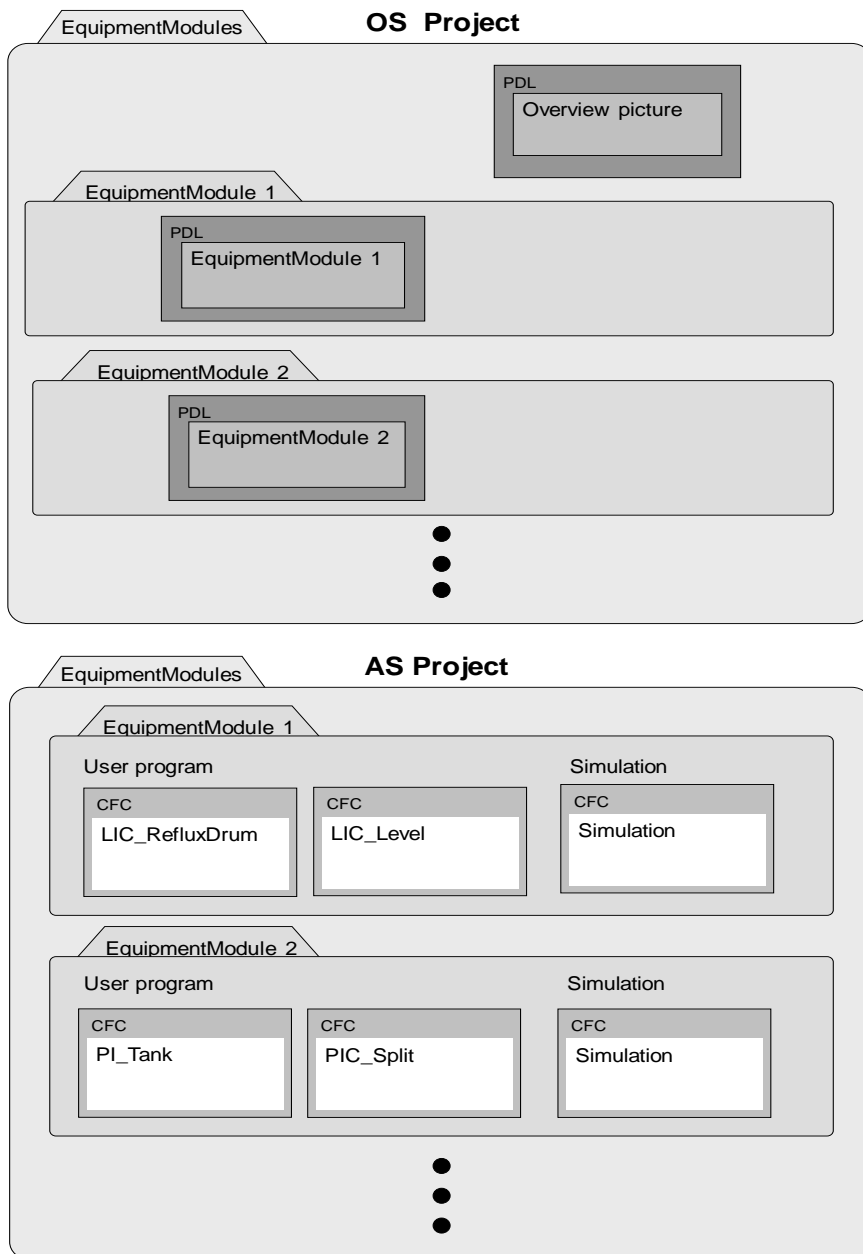
Subsequent letter	Meaning
A	Alarming/Messages
C	Control
F	Fraction
I	Indication
R	Recording/Storage
S	Binary control function or switching function (not safety-oriented) ("switching")
T	Monitoring (transmitter, analog value processing)
H	High
L	Low

## 6.3.2. Plant view

In the plant view, the equipment modules are implemented on two hierarchy levels.

In the "EquipmentModules\_AS\_Prj" AS project, the first hierarchy level is empty and on the lower hierarchy level there is one hierarchy folder for each equipment module that contains the necessary CFC.

On the first hierarchy level of the "EquipmentModules\_OS\_Prj" OS project, there is the overview picture of all the equipment modules "EquipmentModules.pdl". On the lower hierarchy level there is one hierarchy folder for each equipment module that contains a process picture. The illustration below shows the folder structure on a schematic basis, i.e. the designations of the sub-folders differ from the folder designations of the PCS 7 project.



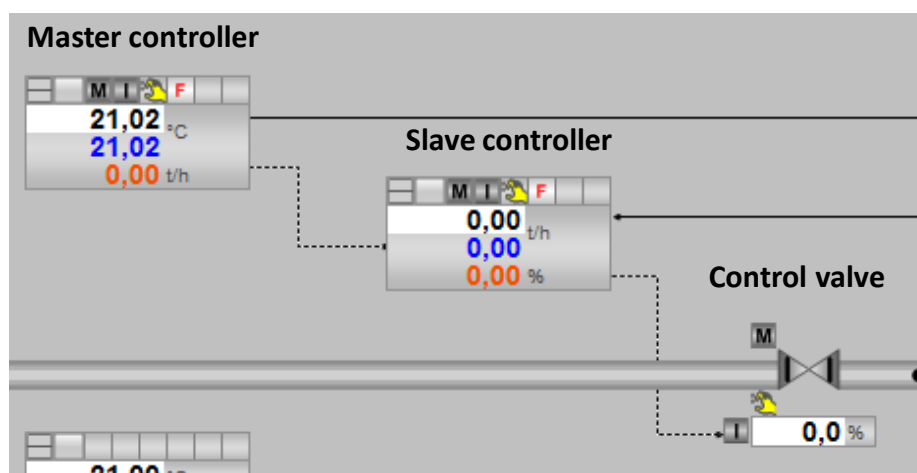
## 6.4. Controllers and control response

The aim of this chapter is to give you an understanding of controller response and the principle of operation in the case of faults or maintenance. To do this, we describe tracking of the manipulated variable in picture form and display the messages or displays on the faceplates in the case of faults.

### 6.4.1. Tracking standard and cascade controllers

Tracking of the manipulated variable is explained using the temperature flow cascade as an example by changing the (internal/external) setpoint specification from the control valve to the master controller and the (manual/automatic) operating mode.

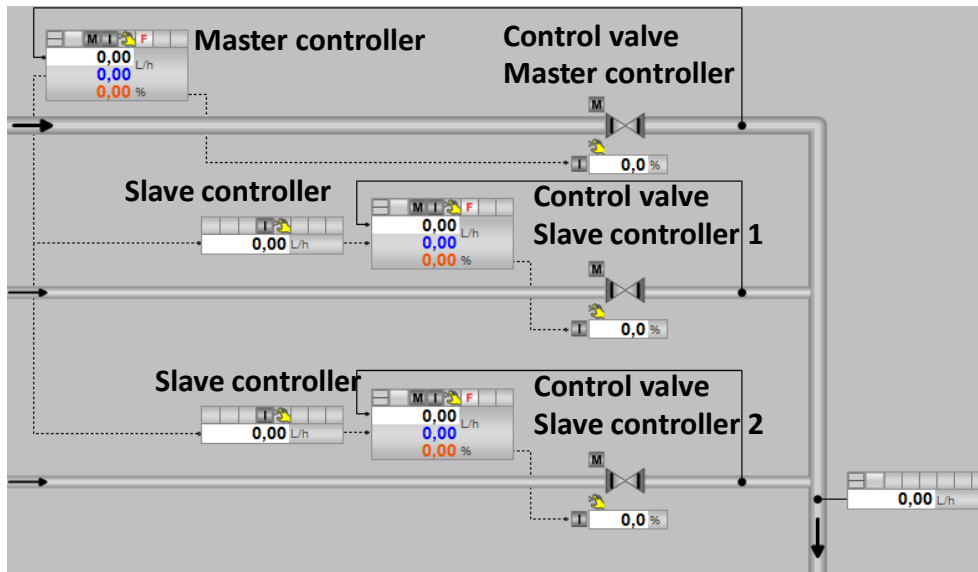
The following applies, in general: A controller must always be set to tracking mode if it does not have access to the following block (follower controller or actuator), because otherwise windup problems occur with controllers with an I component. A controller always has no access to the following block if the following block is not in automatic mode and uses the external setpoint. The tracking value is always selected in such a way that the cascade can be closed again later without jolts.



No.	Master controller	Slave controller	Control valve	Comment
1.	Manual/Internal (Forcing active)	Manual/Internal (Forcing active)	Manual/Internal	
2.	Manual/Internal (Forcing active) <b>Manipulated value 1t/h</b>	Manual/Internal (Forcing active) <b>Manipulated value 20 %</b>	Manual/Internal <b>Manipulated value 20 %</b>	Manipulated value specification 20 % in control valve The manipulated values are tracked automatically
3.	Manual/Internal (Forcing active) Manipulated value 1t/h	Manual/Internal <b>(Forcing canceled)</b> Manipulated value 20 %	<b>Automatic/External</b> Manipulated value 20 %	Operating mode changed in control valve. The control valve applies the tracked (external) manipulated variable on a bumpless basis from the slave controller
4.	Manual/Internal (Forcing active) Manipulated value 1t/h	<b>Automatic/Internal</b> Manipulated value 20 %	Automatic/External Manipulated value 20 %	Operating mode changed in slave controller. No change in behavior.
5.	Manual/Internal <b>(Forcing canceled)</b> Manipulated value 1t/h	Automatic/ <b>External</b> Manipulated value 20 %	Automatic/External Manipulated value 20 %	Setpoint specification changed in slave controller. The slave controller applies the tracked (external) manipulated variable on a bumpless basis from the master controller

## 6.4.2. Tracking ratio controllers

Tracking of the manipulated variable is explained using the "Ratio control" equipment module as an example by changing the (internal/external) setpoint specification from the control valve to the master controller and the (manual/automatic) operating mode.



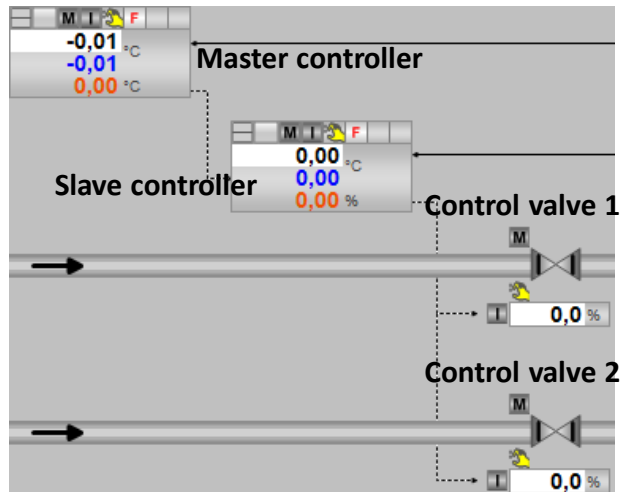
No.	Master controller	Slave controller	Control valve master controller	Control valve slave controller	Comment
1.	Manual/Internal (Forcing active)	Manual/Internal (Forcing active)	Manual/Internal	Manual/Internal	
2.	Manual/Internal (Forcing active) Manipulated value 0.00 l/h	Manual/Internal (Forcing active) <b>Manipulated value</b> 100 l/h	Manual/Internal  Manipulated value 0 %	Manual/Internal  <b>Manipulated</b> <b>value 20 %</b>	Manipulated value specification 20 % in control valve2 The manipulated variable is tracked automatically
3.	Manual/Internal (Forcing active) <b>Manipulated</b> <b>value 600 l/h</b>	Manual/Internal (Forcing canceled) Manipulated value 100 l/h	Manual/ Internal  <b>Manipulated</b> <b>value 30 %</b>	Manual/ Internal  Manipulated value 20 %	Manipulated value specification 30 % in control valve1 The manipulated variable is tracked automatically
4.	Manual/Internal (Forcing active) Manipulated value 600 l/h	Manual/Internal <b>(Forcing canceled)</b> Manipulated value 100 l/h	Manual/ External  Manipulated value 30 %	<b>Automatic/</b> External  Manipulated value 20 %	Operating mode changed in control valve2.
5.	Manual/Internal <b>(Forcing</b> <b>canceled)</b> Manipulated value 600 l/h	Manual/Internal (Forcing canceled) Manipulated value 100 l/h	<b>Automatic/</b> External  Manipulated value 30 %	Automatic/ External  Manipulated value 20 %	Operating mode changed in control valve1.
6.	Manual/Internal (Forcing canceled) Manipulated value 600 l/h	<b>Automatic/</b> External (forcing canceled) <b>Manipulated value</b> 150 l/h	Automatic/ External  Manipulated value 30 %	Automatic/ External  <b>Manipulated</b> <b>value 30 %</b>	Operating mode changed in slave controller. The manipulated variable is tracked automatically

## 6.4.3. Tracking split range temperature

Tracking of the manipulated variable is explained using the split range temperature as an example by changing the (internal/external) setpoint specification from the control valve to the master controller and the (manual/automatic) operating mode. The front part of the cascade with the interaction of master and slave controller works exactly like the normal cascade control in section 6.4.1. In tracking operation, the split-range controller uses the neutral position as the tracking value, because in manual operation or with an internal setpoint of both actuators, combinations of output values can be set that cannot be mapped via the split-range.

### NOTE

When using a split-range rule structure, it is **not** ensured that bumpless return to normal operation is possible.



No.	Master controller	Slave controller	Control valve1	Control valve2	Comment
1.	Manual/Internal (Forcing active)	Manual/Internal (Forcing active)	Manual/ Internal	Manual/ Internal	
2.	Manual/Internal (Forcing active)	Manual/Internal <b>(Forcing canceled)</b>	<b>Automatic/ External</b>	<b>Automatic/ External</b>	Operating mode changed for control valves. No change in behavior.
3.	Manual/Internal <b>(Forcing canceled)</b>	<b>Automatic/ External</b> (Forcing canceled)	Automatic/ External	Automatic/ External	Operating mode changed with slave controller. No change in behavior.
4.	<b>Automatic/ Internal</b> (Forcing canceled) <b>Manipulated variable 30 °C</b>	Automatic/ External	Automatic/ External	Automatic/ External	Operating mode changed with master controller. Manipulated variable specification 30 °C in master controller. The slave controller applies the tracked (external) manipulated variable on a bumpless basis from the master controller.
5.	Manual/Internal (Forcing canceled) Manipulated variable 30 °C	Automatic/ External <b>Manipulated variable 50 °C</b>	Automatic/ External <b>Manipulated variable &gt;= 0 %</b>	Automatic/ External <b>Manipulated variable &gt;= 0 %</b>	Setpoint specification changed in slave controller. The slave controller applies the tracked (external) manipulated variable on a bumpless basis from the master controller.

## 6.4.4. Faults and maintenance for temperature throughflow cascade

In general, a controller cannot work if it does not receive correct actual value of the measured values due to wire break, loose contact, short circuit, bus error, sensor failure or similar. The error case is signaled at the channel block by the output "Bad = true".

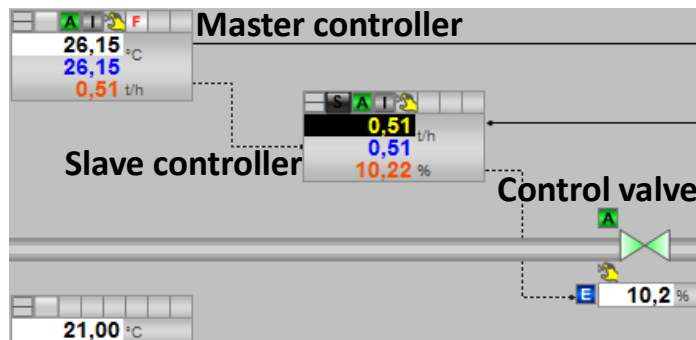
The controller is then put into the fault state (CSF: Control System Fault) by means of an interconnection and allows the operator to set manually the manipulated variable in order to be able to influence at least the process. In case of a fault in the channel to the actuator even this possibility of intervention is no longer available. For the tracking of the master controller, the general rules also valid here: as soon as the slave controller is no longer able to follow commands of the master controller (no matter why, even with CSF in slave controller), the master controller must be taken in tracking to enable later bumpless switching to normal operation.

The tables below describe the way of functioning and generated messages of the individual process tags using the temperature throughflow cascade in case of errors as an example.

The error on the channel block (the Bad output is active) occurs if there is a short-circuit or a wire break on the device, for example.

Maintenance status OoSAct (lies: "Out of Service") occurs if maintenance is being carried out on the device. From the controller's point of view, the sensor state "Out of service" has the same consequences as the measurement loss.

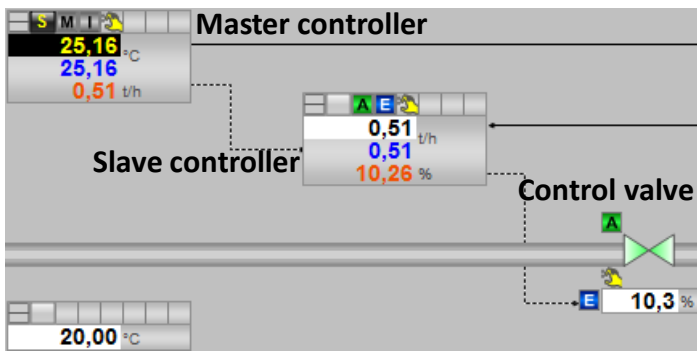
### Faulty slave controller



Master controller	Slave controller	Control valve
Control or manipulated variable specification is not possible since the CSF with the slave controller is forced	<b>CSF puts the controller into disturbance status (external error). Controller switches to manual mode. The manipulated variable for the control valve can be changed</b>	No change in operating mode. The manipulated variable of the slave controller still matches the manipulated variable, MV.

**NOTE** As soon as the CSF on the slave controller is no longer active, it can be switched back to the original operating status (automatic/external).

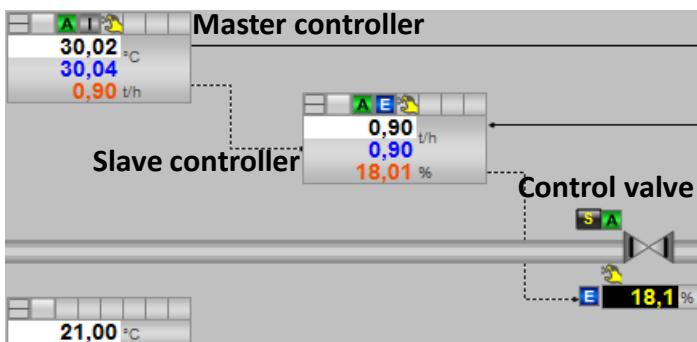
Faulty master controller



Master controller	Slave controller	Control valve
CSF puts the controller into disturbance status (external error). The manipulated variable (MV) can be changed.	The slave controller continues to receive the MV from the master controller	The control valve continues to receive the MV from the slave controller

**NOTE** As soon as the CSF on the master controller is no longer active, it can be switched back to the original operating status (automatic/external).

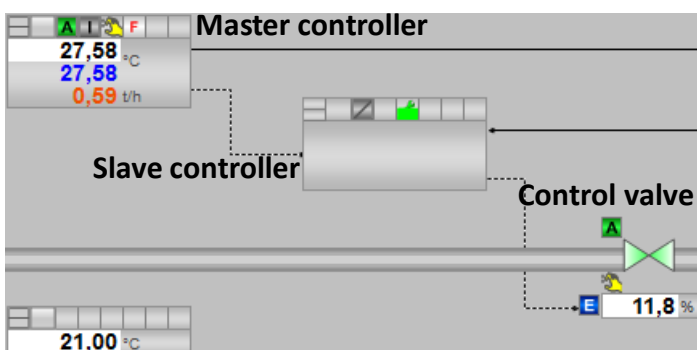
Faulty control valve



Master controller	Slave controller	Control valve
The controller receives the MV in the case of a manual change on the control valve	The controller receives the MV in the case of a manual change on the control valve	CSF puts the valve into disturbance status (external error) The manipulated variable (MV) can be changed (manual)

**NOTE** As soon as the CSF on the control valve is no longer active, it can be switched back to the original operating status (automatic/external).

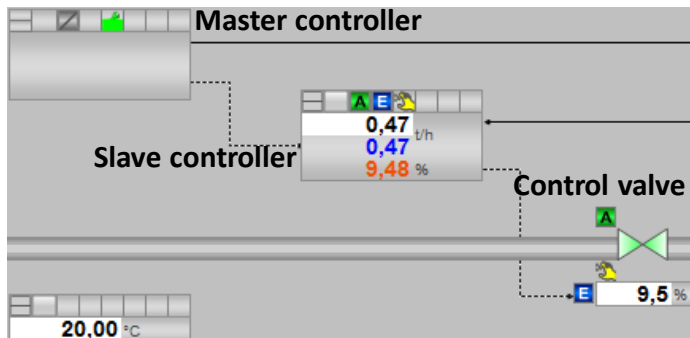
Maintenance status on slave controller



Master controller	Slave controller	Control valve
The controller maintains the old MV until normal operation is re-established or the operator specifies a different MV on the slave controller manually.	<b>The controller cannot be operated due to maintenance.</b> <b>The user can switch to manual mode and specify the MV for the control valve.</b>	The control valve retains the old value while there is no new MV from the slave controller

**NOTE** As soon as the maintenance status is no longer active, the slave controller can be switched back to the original operating status (automatic/external).

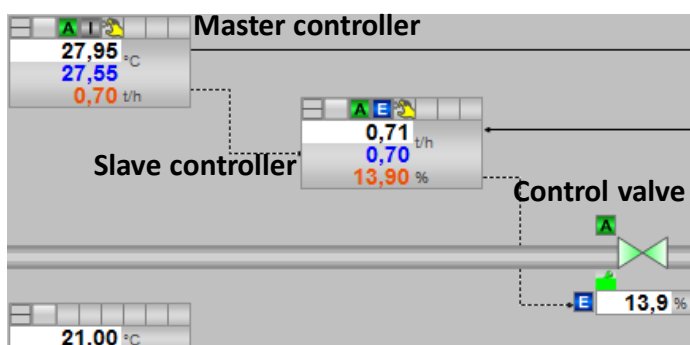
Maintenance status on master controller



Master controller	Slave controller	Control valve
The controller cannot be operated due to maintenance. The user can switch to manual mode and specify the MV for the slave controller.	The controller retains the old value while there is no new MV from the master controller.	The control valve retains the old value while there is no new MV from the slave controller.

**NOTE** As soon as the maintenance status is no longer active, the master controller can be switched back to the original operating status (automatic/external).

Maintenance status on control valve



Master controller	Slave controller	Control valve
Normal operation is possible	Normal operation is possible	<b>Normal operation is still possible.</b> <b>The maintenance status is displayed.</b>



## 6.4.5. Faults and maintenance for ratio controllers

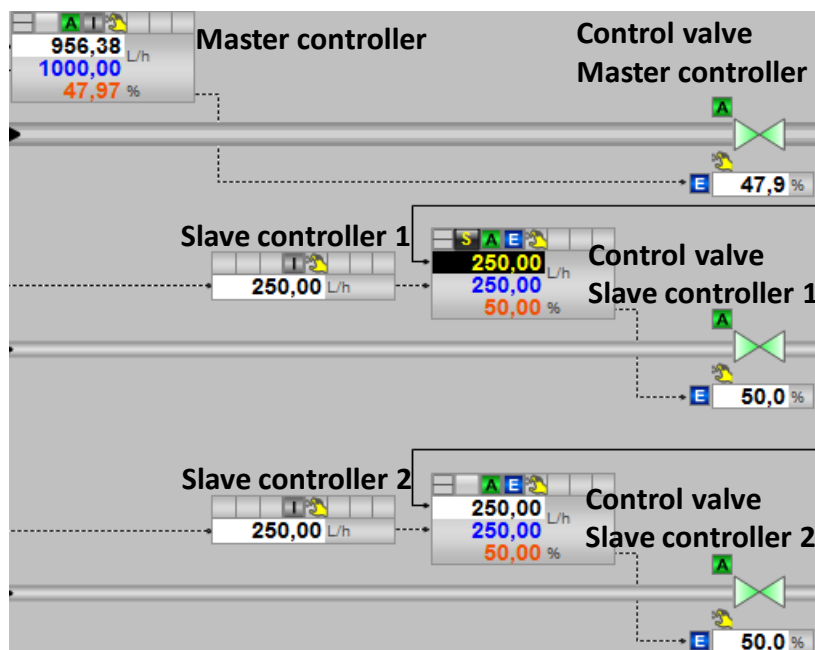
The tables below describe the way of functioning and generated messages of the individual process tags using the ratio controllers in case of errors as an example.

The error on the channel block (the Bad output is active) occurs if there is a short-circuit or a wire break on the device, for example.

Maintenance status OoSAct occurs if maintenance is being carried out on the device.

**NOTE** In the chapter below, we will not consider the second slave controller with control valve, since the behavior matches that of the first slave controller with control valve.

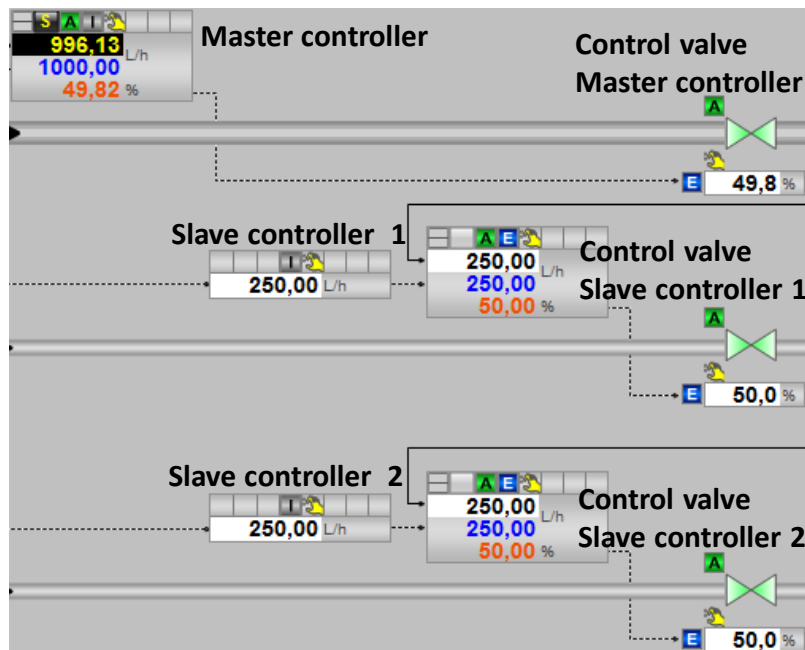
Faulty slave controller



Master controller	Control valve master controller	Slave controller 1	Control valve slave controller 1
The controller functions without limitations.	The control valve functions without limitations.	<b>CSF puts the controller into malfunction status. The MV can be changed.</b>	The control valve retains the old MV until the slave controller specifies a new value.

**NOTE** As soon as the CSF on the slave controller is no longer active, it can be switched back to the original operating status (automatic/external).

Faulty master controller

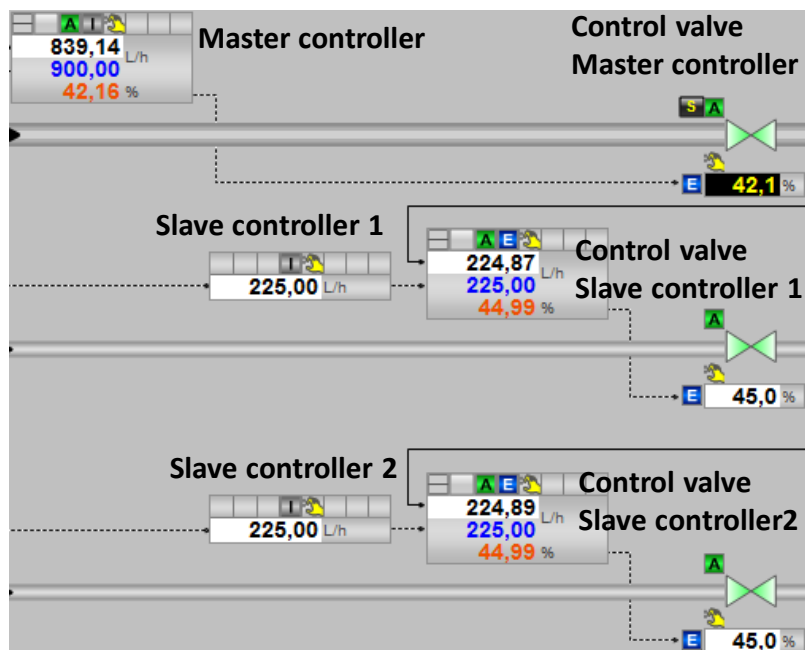


Master controller	Control valve master controller	Slave controller 1	Control valve slave controller 1
CSF puts the controller into malfunction status. The manipulated variable can be changed.	The control valve functions without limitations.	The controller functions without limitations.	The control valve functions without limitations.

**NOTE**

As soon as the CSF on the master controller is no longer active, the master controller is back in operating condition

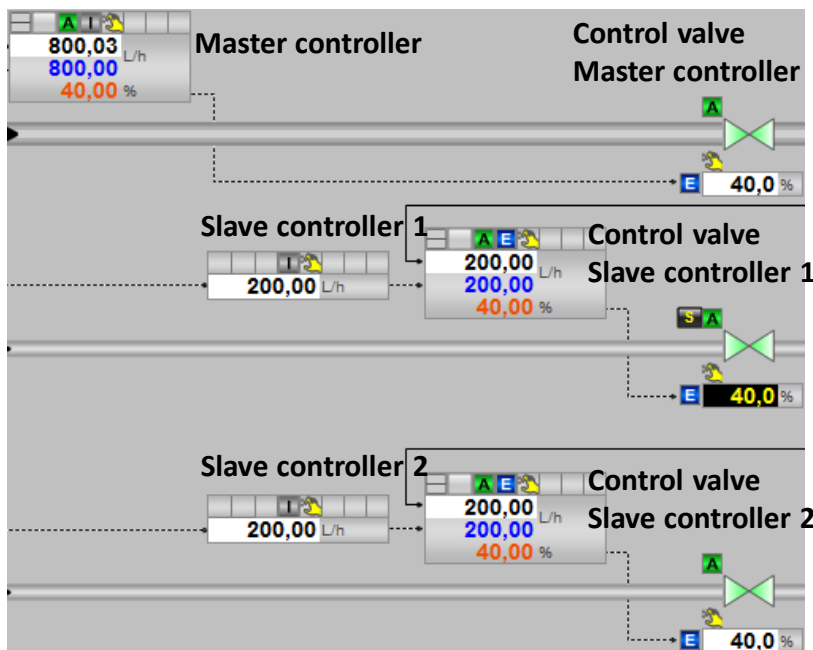
Faulty control valve of master controller



Master controller	Control valve master controller	Slave controller	Control valve slave controller
The controller functions without limitations.	<b>CSF puts the control valve of the master controller into malfunction status. The valve functions without limitations.</b>	The controller functions without limitations.	The valve functions without limitations.

**NOTE** As soon as the CSF on the master controller's control valve is no longer active, it is back in Automatic/External mode.

Faulty control valve of slave controller

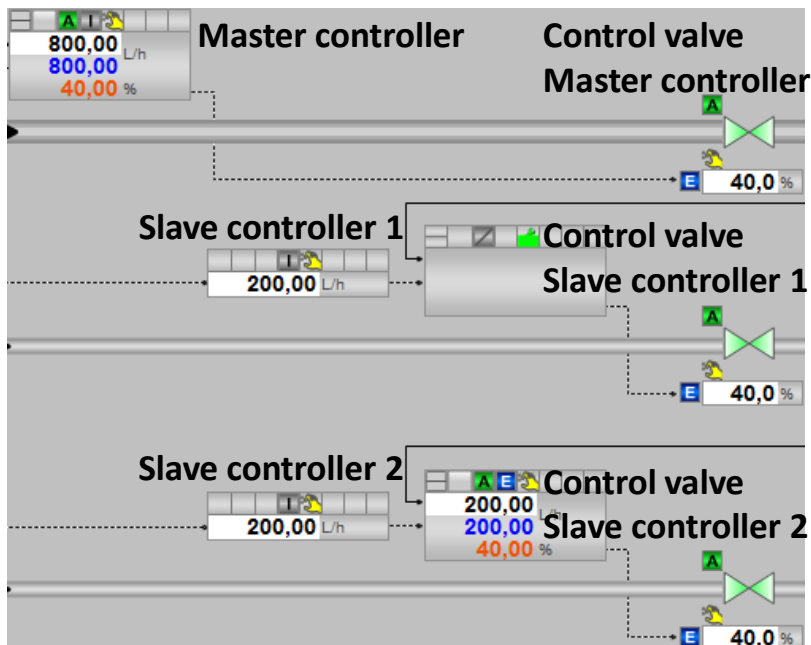


Faulty control valve of slave controller

Master controller	Control valve master controller	Slave controller	Control valve slave controller
The controller functions without limitations.	The valve functions without limitations.	The controller functions without limitations.	<b>CSF puts the control valve of the slave controller into malfunction status. The valve functions without limitations.</b>

**NOTE** As soon as the CSF on the slave controller's control valve is no longer active, it is back in Automatic/External mode.

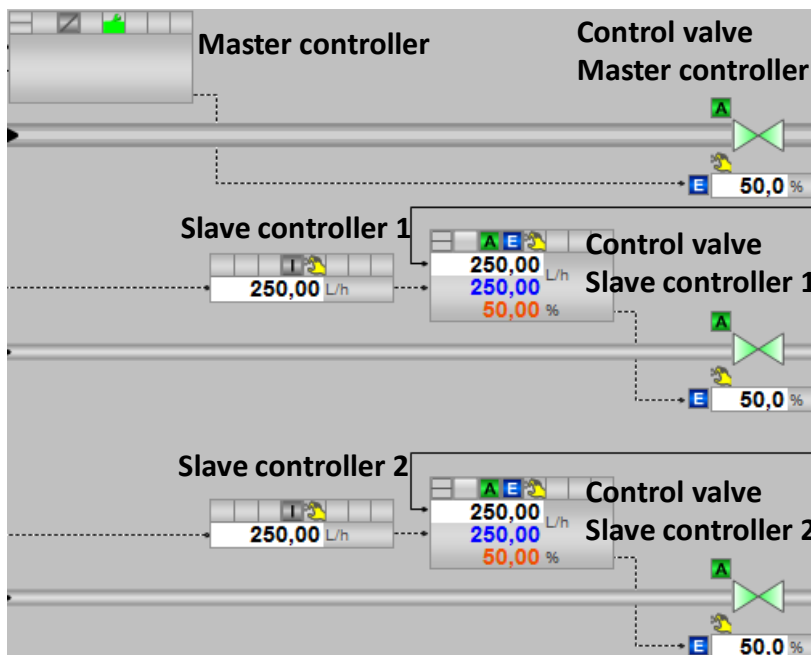
Maintenance status on slave controller



Master controller	Control valve master controller	Slave controller	Control valve slave controller
The controller functions without limitations.	The valve functions without limitations.	<b>The controller cannot be operated due to maintenance.</b> The user can switch to manual mode and change the MV.	The control valve retains the old value until the slave controller specifies a new MV.

**NOTE** As soon as the maintenance status is no longer active, the slave controller can be switched back to the original operating status (automatic/external).

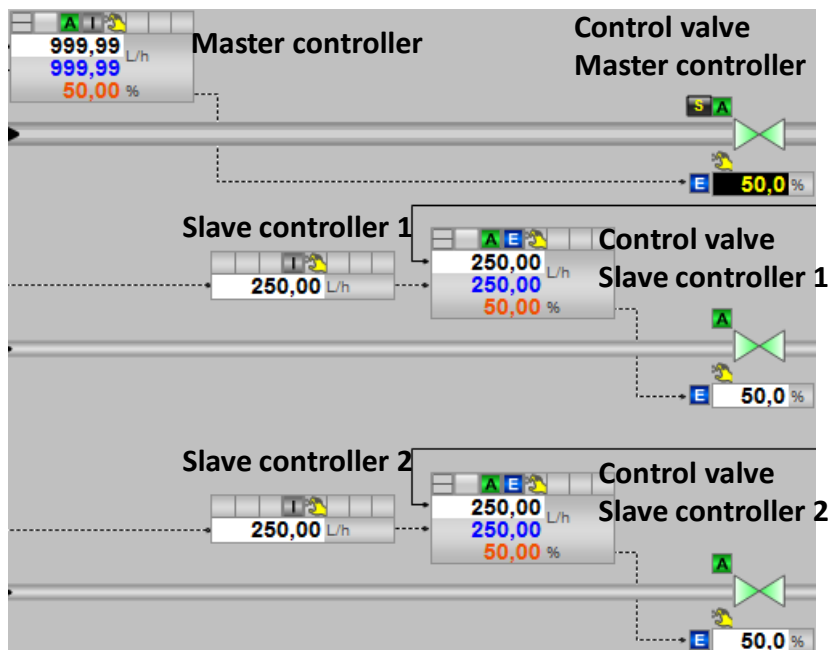
Maintenance status on master controller



Master controller	Control valve master controller	Slave controller	Control valve slave controller
The controller cannot be operated due to maintenance. The user can switch to manual mode and change the MV.	The control valve retains the old value until the slave controller specifies a new MV.	The controller functions without limitations.	The valve functions without limitations.

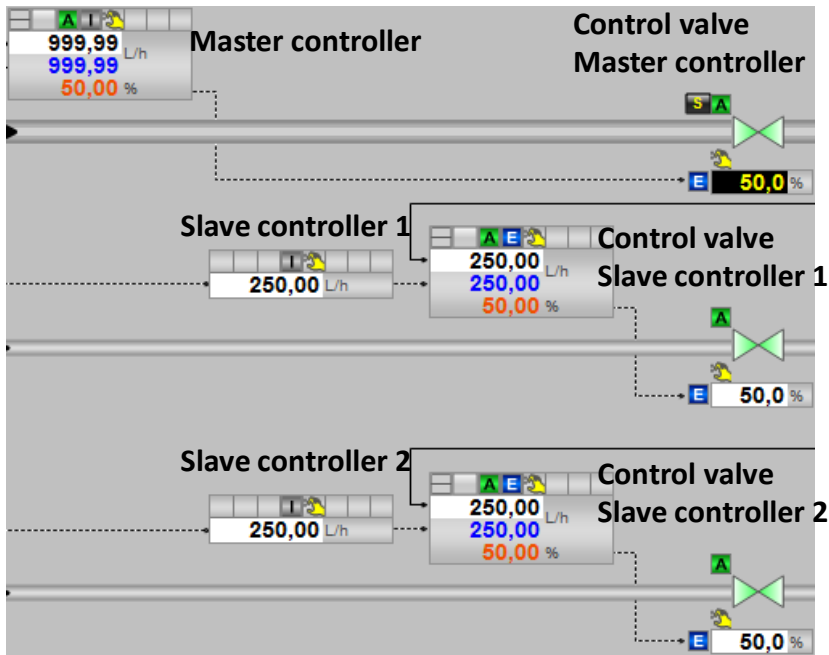
**NOTE** As soon as the maintenance status is no longer active, the master controller can be switched back to the original operating status (automatic).

Maintenance status on control valve of master controller



Master controller	Control valve master controller	Slave controller	Control valve slave controller
The controller functions without limitations.	The valve displays the maintenance status and functions without limitations.	The controller functions without limitations.	The valve functions without limitations.

Maintenance status on control valve of slave controller



Master controller	Control valve master controller	Slave controller	Control valve slave controller
The controller functions without limitations.	The valve functions without limitations.	The controller functions without limitations.	<b>The valve displays the maintenance status and functions without limitations.</b>

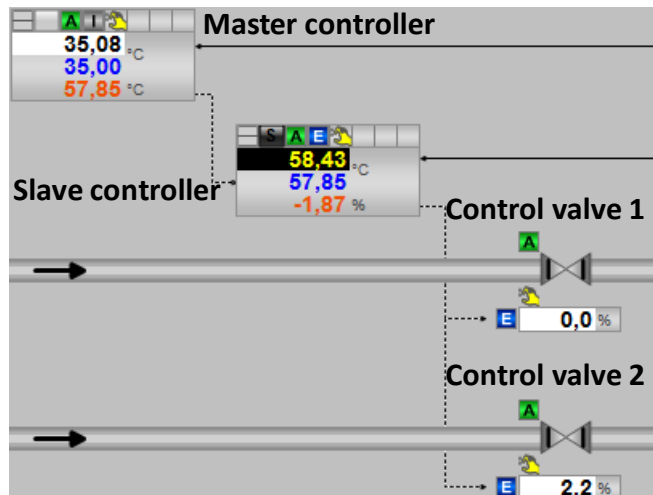
## 6.4.6. Faults and maintenance of split range temperature

The tables below describe the way of functioning and generated messages of the individual process tags using the split range temperature controller in case of errors as an example.

The error on the channel block (the Bad output is active) occurs if a short-circuit or a wire break occurs on the device, for example.

Maintenance status OoSAct occurs if maintenance is being carried out on the device.

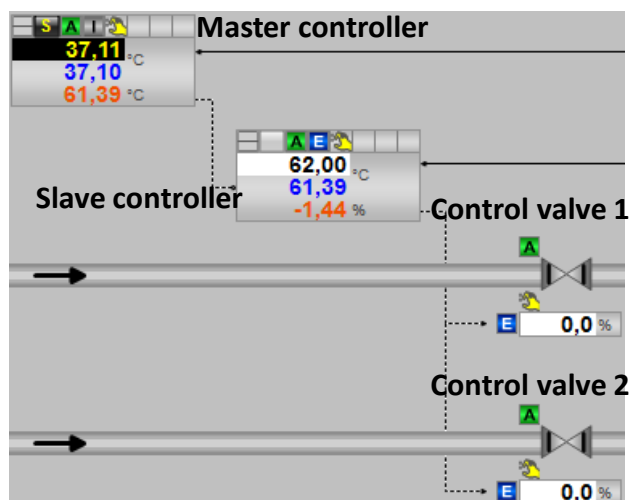
### Faulty slave controller



Master controller	Slave controller	Control valve1	Control valve2
The controller functions without limitations.	<b>CSF puts the controller into malfunction status.</b> The MV can be changed.	The valve functions without limitations.	The valve functions without limitations.

**NOTE** As soon as the CSF on the slave controller is no longer active, it can be switched back to the original operating status (automatic/external).

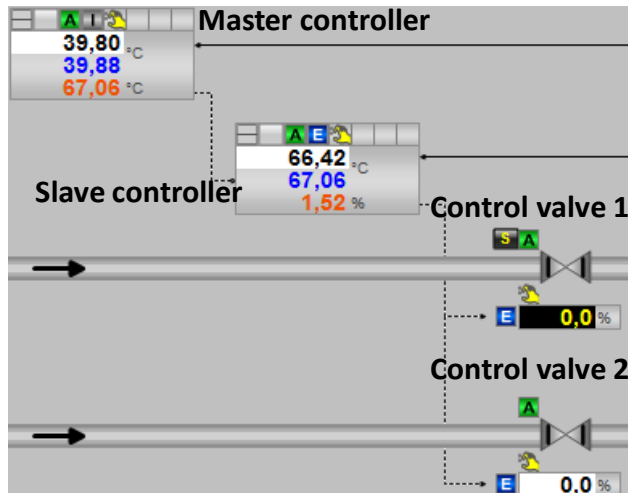
### Faulty master controller



Master controller	Slave controller	Control valve1	Control valve2
CSF puts the controller into malfunction status. The MV can be changed.	The controller retains the last manipulated variable that was present until the master controller specifies a new value.	The valve functions without limitations.	The valve functions without limitations.

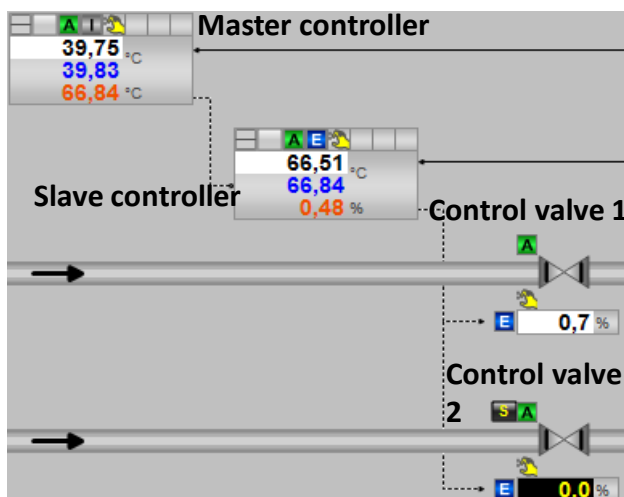
**NOTE** As soon as the CSF on the master controller is no longer active, it can be switched back to the original operating status (automatic).

Faulty control valve 1



Master controller	Slave controller	Control valve1	Control valve2
The controller functions without limitations.	The controller functions without limitations.	CSF puts the valve into malfunction status. Operation and the MV can be changed.	The valve functions without limitations.

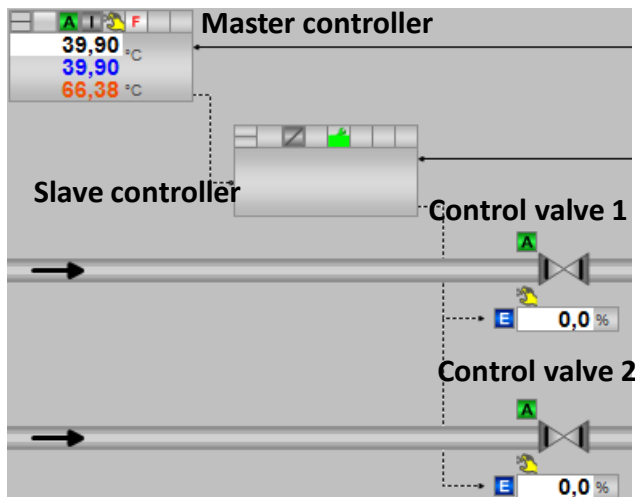
Faulty control valve 2



Master controller	Slave controller	Control valve1	Control valve2
The controller functions without limitations.	The controller functions without limitations.	The valve functions without limitations.	CSF puts the valve into malfunction status. The operating mode and the MV can be changed.



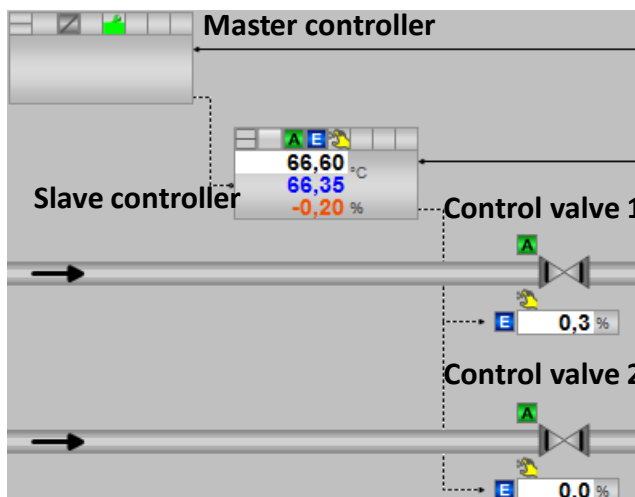
Maintenance status on slave controller



Master controller	Slave controller	Control valve1	Control valve2
The controller cannot affect the process while the slave controller is being maintained.	<b>The controller cannot be operated due to maintenance.</b> The user can switch to manual mode and specify the MV for the control valve.	The valve functions without limitations.	The valve functions without limitations.

**NOTE** As soon as the maintenance status is no longer active, the slave controller can be switched back to the original operating status (automatic/external).

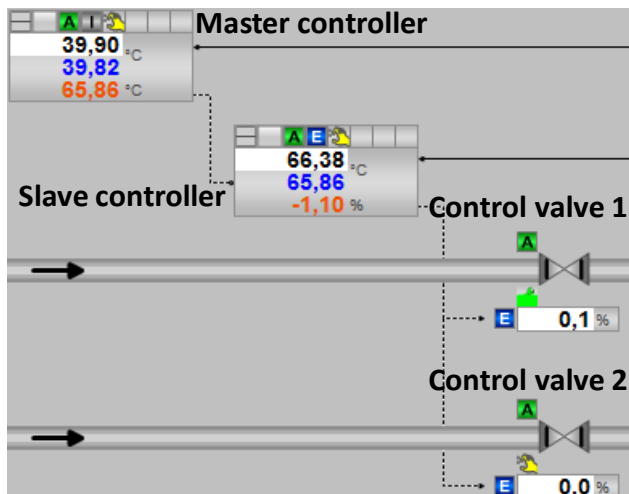
Maintenance on master controller



Master controller	Slave controller	Control valve1	Control valve2
The controller cannot be operated due to maintenance. The user can switch to manual mode and specify the MV.	The controller retains the old value while there is no new MV from the master controller.	The valve functions without limitations.	The valve functions without limitations.

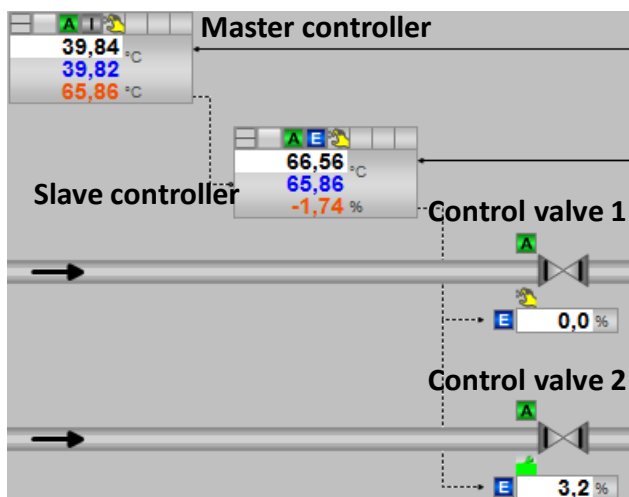
**NOTE** As soon as the maintenance status is no longer active, the master controller can be switched back to the original operating status (automatic).

Maintenance on control valve 1



Master controller	Slave controller	Control valve1	Control valve2
The controller functions without limitations.	The controller functions without limitations.	The valve displays the maintenance status and functions without limitations.	The valve functions without limitations.

Maintenance on control valve 2



Master controller	Slave controller	Control valve1	Control valve2
The controller functions without limitations.	The controller functions without limitations.	The valve functions without limitations.	The valve displays the maintenance status and functions without limitations.

## 6.5. Block description of "pHTitrBlock"

### Function description

The block is used to convert pH values to concentration differences. To do this, you must enter process-specific characteristics of the titration curve in the form of parameters for the pH amplitude and buffer effect ( $\alpha$ ). The titration curve describes the relationship between the pH value and the concentration difference between  $H^+$  (or  $H_3O^+$ ) ions (acidic) and  $OH^-$  ions (alkaline) in the solution. For a given combination of chemicals, you can determine them in an experiment by adding an acid or an alkali (neutralizer) in small steps. After each small dose, you mix the solution well, wait for the neutralization reaction, and make a note of the new pH value.

For the equipment modules for pH value control, you use the trigonometric function below as an approximation of the titration curve for conversion:

$$pH = 7 + \frac{2pH_{ampl}}{\pi} \cdot \arctan\left(\alpha \cdot \frac{\Delta c}{10^6}\right)$$

This characteristic curve is inverted to convert pH values to concentration differences.

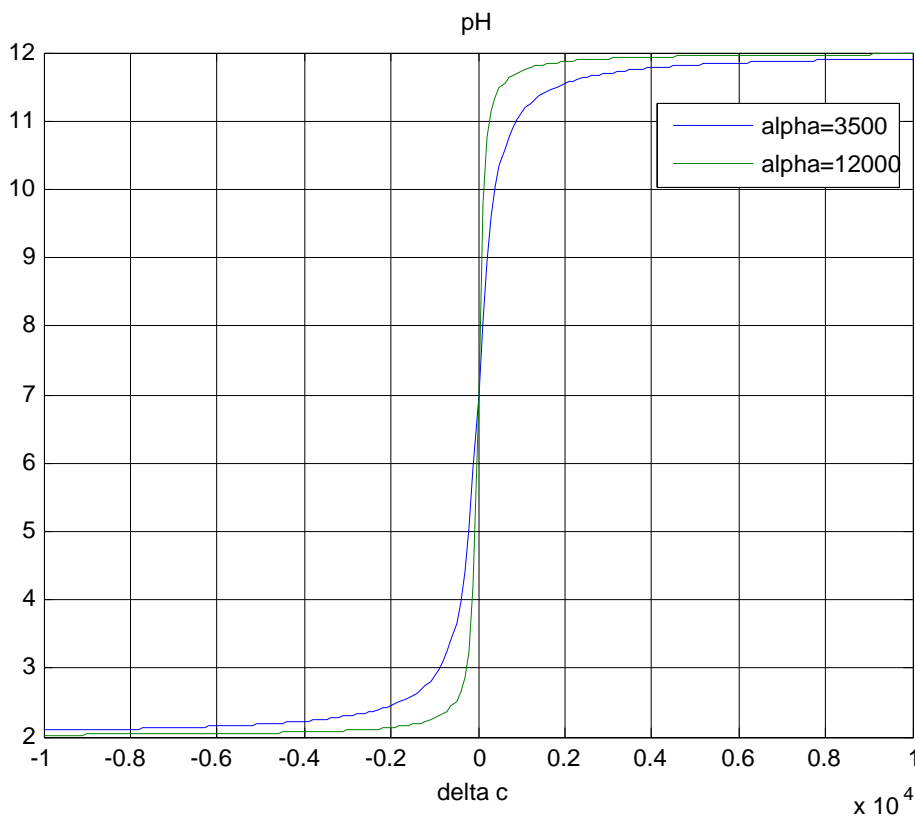
$$\Delta c = \frac{1}{\alpha} \cdot \tan\left(\frac{\pi}{2pH_{ampl}} \cdot (pH - 7)\right) \cdot 10^6$$

#### NOTE

Conversion is carried out in the two blocks below that are a component of the "pHTitrBlock" and are included in the master data library:

- FB1025 "Titr\_pH" for converting the concentration difference to the  $\rightarrow$ pH value
- FB1026 "TitrDeltaC" for converting the pH value to the  $\rightarrow$ concentration difference

Titration curve for various highly buffered solutions;  $pH_{ampl}=5$



In the titration curve illustration, the neutral zone is at 7 pH with the maximum excursion (amplitude) of 5. Typical values of between 3500 and 12000 are present for the steepness of the characteristic curve in the neutral point (parameter  $\alpha$ ).

**NOTICE**

Use in a productive environment is conditional upon knowing the titration curve that must be entered in the block.

The parameters include:

- the amplitude area  $pH_{amp}$  to be passed through on the pH value scale
- the buffer parameter  $\alpha$  (alpha) as a measure of the steepness of the characteristic curve in the neutral point

**Inputs**

Input	Data type	Description
CV	STRUCT ->Real ->Byte	pH actual value
DV	STRUCT ->Real ->Byte	pH value of the disturbance variable
SP	STRUCT ->Real ->Byte	pH setpoint (specified by OpAnL operator control block oper SFC, for example)
Alpha	STRUCT ->Real ->Byte	Measure of the steepness of the characteristic curve in the neutral point
Ampl_pH	STRUCT ->Real ->Byte	The amplitude range that is to be crossed
MV	STRUCT ->Real ->Byte	Manipulated variable of the controller
Feed_PV_Out	STRUCT ->Real ->Byte	Inflow of the input material (disturbance variable)
Feed_Scale	STRUCT ->Real ->Real	Scaling of the inflow (ScaleOut)

Conversion of the concentration differences for inputs "CV", "DV", and "SP" is carried out based on parameters "Alpha" and "Ampl\_pH".

**Outputs**

Output	Data type	Description
CV_Out	STRUCT ->Real ->Byte	Concentration difference of the pH actual value
DV	STRUCT ->Real ->Byte	Concentration difference of the pH value of the disturbance variable
SP	STRUCT ->Real ->Byte	Concentration difference of the pH setpoint

Output	Data type	Description
MVHiLim	STRUCT ->Real ->Byte	Variable upper limit value of manipulated variable MV depending on the feed amount of input material ( $MVHiLim = 100/Feed\_PV\_Out/Feed\_Scale.Max$ )
MV_Valve	STRUCT ->Real ->Byte	Variable manipulated variable (to the valve process tag) depending on the feed amount of input material ( $MV\_Valve = Feed\_PV\_Out/Feed\_Scale.Max * MV$ )

Interconnection of the inputs and outputs of the manipulated variables/disturbance variables ("MV", "Feed\_PV\_Out", "Feed\_Scale", "MVHiLim", "MV\_Valve") is carried out if it is intended to compensate the feed amount as a disturbance variable.

**NOTE**

The output variable of the controller (what you can think of as a "concentration") is multiplied by the (standardized) feed amount of the waste water (input material) to calculate a measure of the required amount of neutralizer. If manipulated variable limitation in the controller itself were to be constant, this would result in it only being possible to use the dosing valve for complete control at maximum waste water flow through. One remedy is to interconnect MV1HiLim dynamically in dependence on the feed amount.

## 6.6. Block description of "SimpHTitr"

### Function description

The block is used to calculate a pH value based on process-specific characteristics like the titration curve of the process, the inflow amounts, and the pH values of the input material and the neutralizer, for example. The titration curve describes the relationship between the pH value and the concentration difference of the supplied neutralizer.

### Inputs

Input	Data type	Description
Feed_pH	STRUCT ->Real ->Byte	pH value of the input material
Alpha	STRUCT ->Real ->Byte	Measure of the steepness of the characteristic curve in the neutral point
Ampl_pH	STRUCT ->Real ->Byte	The amplitude range that is to be crossed
Neutr_MV	STRUCT ->Real ->Byte	Manipulated variable of the controller for the neutralizer
Neutr_Lag	Real	Delay of the manipulated variable (neutralizer)
Neutr_Factor	Real	Factor value for inflow of the neutralizer
Feed_PV	STRUCT ->Real ->Byte	inflow amount of the input material
pH_DeadTime	Real	Time-delayed signal output in seconds (deadtime)

### NOTICE

When using the deadtime ( $\text{pH\_DeadTime} > 0$ ), you must use a multi-variable controller (ModPreCon block) for compensation and feedforward injection of disturbance variable.

### Outputs

Output	Data type	Description
pH	STRUCT ->Real ->Byte	pH simulation value

To calculate the pH value, you carry out the following calculation steps:

1. Determine the products (multiplication) from the concentration differences and inflow amounts of the input material and the neutralizer
2. Determine the overall inflow amount
3. Calculate the factor (proportional concentration difference) from the products and the overall inflow amount
4. Convert the concentration difference to the pH actual value

In the simulation, you can adapt both the process-specific characteristics of the titration curve and the effect of the values of feedforward injection of disturbance variable (change the pH values of the input material by  $\pm 1$ ) and the variable throughflow amounts (change the inflow amount by  $\pm 500$  mol/L).

## 6.7. Block description of "ComStruIn" and "ComStruOut"

### Function description

The blocks are used for standardized interconnection of process tags (controllers with a valve process tag) or for setting up cascade controllers. All relevant signals from a process tag are grouped into one structure, so that only a single interconnection (of the structure) is required, instead of numerous individual cross-system interconnections.

Connections from the valves or controllers are present at the inputs of the blocks, which are then connected via the cross-chart interconnections outputs structure to the target process tag (i.E. slave controller or valve).

### Inputs "ComStruIn"

Input	Data type	Description
ReStru1 bis ReStru6	STRUCT ->Real ->Byte	e.g. transmission von process-, parameter- or limit values
BoStru1 bis BoStru6	STRUCT ->Bool ->Byte	e.g. setpoint, out of service and interlock
Int1 and Int2	INT	e.g. process value unit
Scale1 and Scale2	STRUCT ->Real ->Real	e.g. process value scale

### Outputs "ComStruIn"

Output	Data type	Description
Out. BoStru1-6 Int1-2 ReStru1-6 Scale1-2	STRUCT ->Real ->INT ->Real ->Real	Structure for connection to Control module

The ComStuOut block is the opposite to ComStruIn. It deconstructs the cross-chart interconnections input structure from the signal source into the original individual variables, which can be used individually in the target process tags.

### Inputs "ComStruOut"

Input	Data type	Description
In. BoStru1-6 Int1-2 ReStru1-6 Scale1-2	STRUCT ->Real ->INT ->Real ->Real	Structure for connection to Control module

### Outputs "ComStruOut"

Output	Data type	Description
ReStru1 bis ReStru6	STRUCT ->Real ->Byte	e.g. transmission von process-, parameter- or limit values

<b>Output</b>	<b>Data type</b>	<b>Description</b>
BoStru1 bis BoStru6	STRUCT ->Bool ->Byte	Condition of MV output drive/channel block
Int1 and Int2	INT	e.g. process value unit
Scale1 and Scale2	STRUCT ->Real ->Real	e.g. process value scale



# 7. Appendix

## 7.1. Service and support

### SiePortal

The integrated platform for product selection, purchasing and support - and connection of Industry Mall and Online support. The SiePortal home page replaces the previous home pages of the Industry Mall and the Online Support Portal (SIOS) and combines them.

- Products & Services  
In Products & Services, you can find all our offerings as previously available in Mall Catalog.
- Support  
In Support, you can find all information helpful for resolving technical issues with our products.
- mySieportal  
mySiePortal collects all your personal data and processes, from your account to current orders, service requests and more. You can only see the full range of functions here after you have logged in.

You can access SiePortal via this address: [sieportal.siemens.com](https://sieportal.siemens.com)

### Industry Online Support

Industry Online Support is the previous address for information on our products, solutions and services.

Product information, manuals, downloads, FAQs and application examples - all information is available with just a few mouse clicks: [support.industry.siemens.com](https://support.industry.siemens.com)

### Technical Support

The Technical Support of Siemens Industry provides you fast and competent support regarding all technical queries with numerous tailor-made offers – ranging from basic support to individual support contracts.

Please send queries to Technical Support via Web form: [support.industry.siemens.com/cs/my/src](https://support.industry.siemens.com/cs/my/src)

### SITRAIN – Digital Industry Academy

We support you with our globally available training courses for industry with practical experience, innovative learning methods and a concept that's tailored to the customer's specific needs.

For more information on our offered trainings and courses, as well as their locations and dates, refer to our web page: [siemens.com/sitrain](https://siemens.com/sitrain)

### Industry Online Support app

You will receive optimum support wherever you are with the "Industry Online Support" app. The app is available for iOS and Android:



## 7.2. Links and literature

No.	Topic
111	Siemens Industry Online Support <a href="https://support.industry.siemens.com">https://support.industry.siemens.com</a>
121	Link to this entry page of this application example <a href="https://support.industry.siemens.com/cs/ww/en/view/53843373">https://support.industry.siemens.com/cs/ww/en/view/53843373</a>
131	SIMATIC PCS 7 overview (collection of links for FAQ, manuals, compendium, forum, application examples and multimedia) <a href="https://support.industry.siemens.com/cs/ww/en/view/63481413">https://support.industry.siemens.com/cs/ww/en/view/63481413</a>
141	Controller optimization with the PID Tuner <a href="https://support.industry.siemens.com/cs/ww/en/view/8031495">https://support.industry.siemens.com/cs/ww/en/view/8031495</a>
151	Model Predictive Control including integral transfer functions <a href="https://support.industry.siemens.com/cs/ww/en/view/42200753">https://support.industry.siemens.com/cs/ww/en/view/42200753</a>
161	Configuration of Cascade Control <a href="https://support.industry.siemens.com/cs/ww/en/view/43033319">https://support.industry.siemens.com/cs/ww/en/view/43033319</a>
171	PCS 7 Unit Template "Stirred Tank Reactor" using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/60546560">https://support.industry.siemens.com/cs/ww/en/view/60546560</a>
181	PCS 7 Unit Template "Fermenter" using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/68098270">https://support.industry.siemens.com/cs/ww/en/view/68098270</a>
191	PCS 7 Unit Template "Distillation Column" using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/48418663">https://support.industry.siemens.com/cs/ww/en/view/48418663</a>
1101	PCS 7 Unit Template "Dryer" using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/74747848">https://support.industry.siemens.com/cs/ww/en/view/74747848</a>
1111	PCS 7 Unit Template "Polymerization Reactor" using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/84061788">https://support.industry.siemens.com/cs/ww/en/view/84061788</a>
1121	How do you procure documentation for PCS 7 (including the PCS 7 Manual Collection)? <a href="https://support.industry.siemens.com/cs/ww/en/view/59538371">https://support.industry.siemens.com/cs/ww/en/view/59538371</a>

## 7.3. Change documentation

Version	Date	Modifications
V1.0	12/2011	First version
V1.1	04/2012	Valid for PCS 7 V7.1.3 and PCS 7 V8.0
V1.2	06/2012	Corrections and comments from suggestions
V2.0	06/2013	Expansion of the Val process tag type, new CTRL process tag types, additional equipment modules for pH value control
V2.1	10/2013	New process tag types (CTRL; AMon and MOT) for multi-variable control and drives inserted. Additional Links.
V2.2	04/2014	Equipment module "Temperature-Flow-Cascade" added.
V3.0	09/2016	Update for PCS 7 V8.2
V4.0	11/2017	Update for PCS 7 V9.0 Modification of the "Level control" equipment module New equipment modules added: <ul style="list-style-type: none"> <li>• Buffer level control by means of "Buffer-Control" feedforward control</li> <li>• "Stream-Control" coarse/fine flow control</li> </ul>
V5.0	05/2019	Update for PCS 7 V9.0 SP1, cross reference for the CMT on the BCM Library, new equipment module Gradient limits in actuators "Gradient-Limit"
V5.1	10/2021	Update for PCS 7 V9.1
V5.2	09/2023	Update to new template