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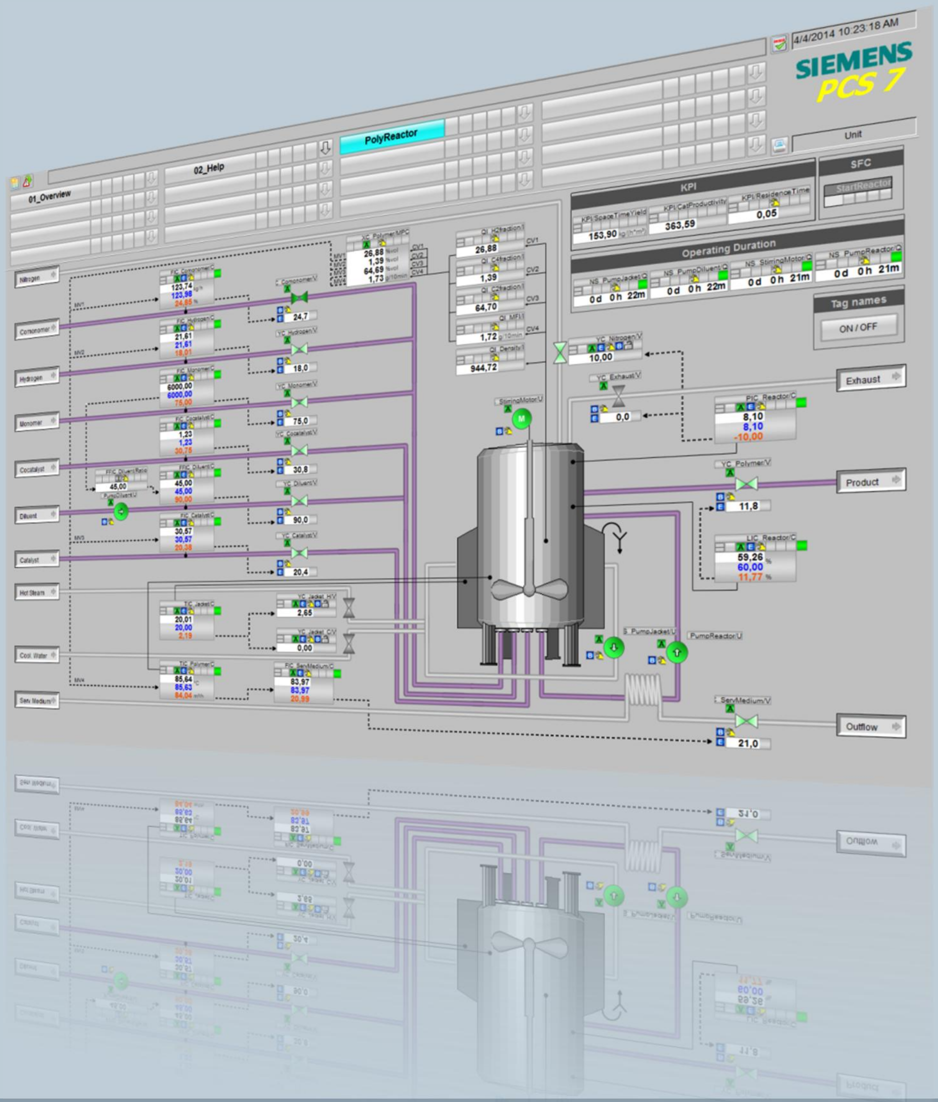

Application description • 09/2015

PCS 7 Unit Template "Polymerization Reactor" using the example of the Chemical Industry

SIMATIC PCS 7

https://support.industry.siemens.com/cs/ww/en/view/84061788

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1 Task and solution

1.1 Task

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.

This includes the configuring of the plant according to the physical model of the ISA 106 standard. This specifies the lower four levels, i.e. plant, unit, plant unit and control module. A plant always consists of units. The units can, in turn, comprise plant units which can be automated by equipment modules.

1.2 Solution

1.2.1 Unit Polymerization reactor

A polymerization reactor is an integral part of many chemical processes. Polymerization reactors can be designed for continuous as well as discontinuous operation with different volumes. The selection of a specific reactor is based on typical specifications which include:

- Production volume and polymer formation
- Reaction rates, aggregate states of monomers, comonomers and polymers
- Viscosity, thermal stability

This application example contains a polymerization reactor with circulation cooling for continuous operation.

During the manufacturing process of polymers, the monomer, comonomer, hydrogen reactants as well as the catalyst and cocatalyst, among others, are added and stirred in the reactor. The use of an MPC control (Model Predictive Control), improves the quality of the manufacturing process or the product.

1.2.2 Description of the complete solution

The unit template "polymerization reactor" contains pre-made, standardized and ready-interconnected equipment modules and process tag types. Using this sample solution as a basis, numerous instances with different parameter assignments can be generated with adapted characteristics to be widely integrated in automation solutions. The PCS 7 project is configured to be hardware-independent and can be flexibly incorporated in existing projects.

The unit template "polymerization reactor" has been implemented as a PCS 7 multiproject as follows:

- One project for the automation system (AS) and one project for the operator station (OS) are respectively contained in the component view.
- A hierarchy folder has been set up in the technical hierarchy for each technical function of the polymerization reactor.

In the AS project, all open- and closed-loop control functions are implemented in the form of CFC (Continuous Function Chart) charts. Furthermore, the AS project also contains a hierarchy folder with simulation charts that simulate a procedure, e.g. the filling level change, within a technical function.

All equipment modules are available in the project's master data library as process tag types and contain function blocks of the PCS 7 Advanced Process Library (APL) and of the Industry Library (IL).

The OS project comprises the visualization of the polymerization reactor with all equipment modules and shows:

- A schematic structure of a polymerization reactor
- The relevant parameters (KPI: Key Performance Indicators)
- The procedural control of a continuous production process

Differentiation

This automation solution is designed for a polymerization reactor in the continuous or semi-continuous operation. During semi-continuous operation different sorts (Grades) of a polymer are alternately produced in a reactor. The grade change requires a change in the reaction conditions during the running process. The automation of the grade change is a particularly challenging technical control task. The unit template could also be adapted for batch operation. In batch operation, the specifications for the quantities of raw materials and the product discharge are done through a recipe control. However, it should be checked whether non-linearities of the process dynamics require special adaptations to the regulatory approach, especially for the start-up phase of the reaction.

In the template, the technical process within the polymerization reactor is only simulated as a much simplified and linearized process. After the simulation has been extended, the unit template could also be used within the framework of an operator training system.

Required experience

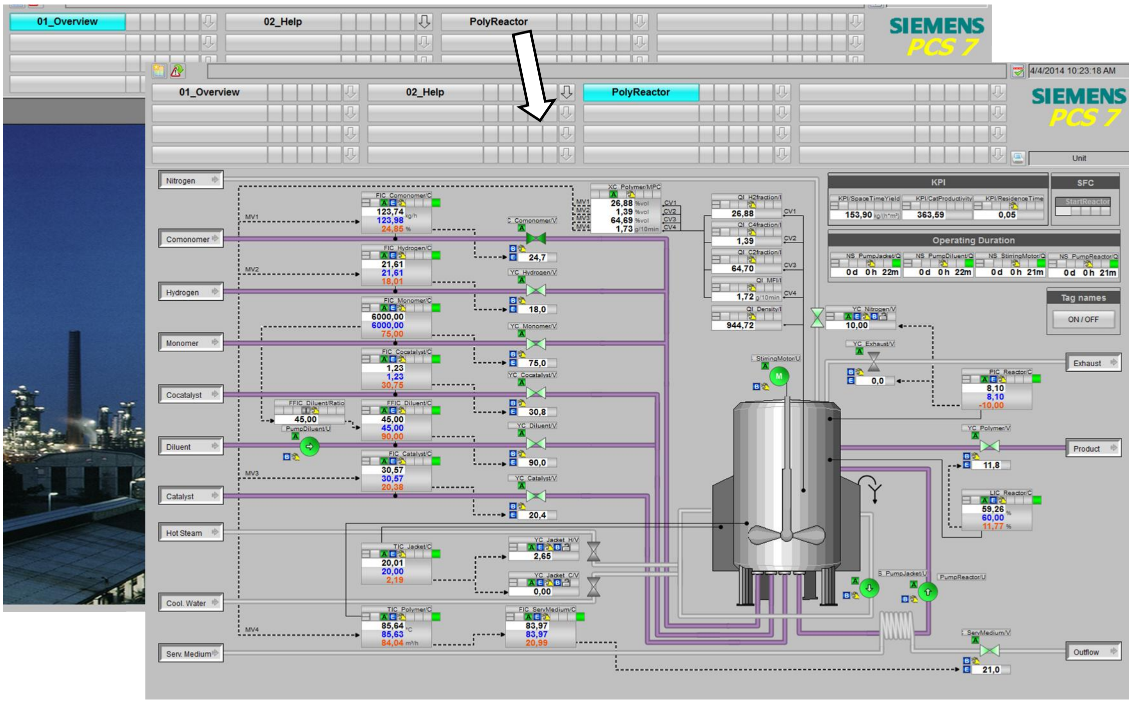
Fundamental knowledge of the following specialist fields is a prerequisite:

- Engineering with SIMATIC PCS 7 and APL
- Knowledge of control technology
- Basic knowledge of process technology
- An understanding of the concept of the equipment modules

1.2.3 Core functionality

The individual parts of a polymerization reactor are described in the following. The entry point is the process picture of the visualization screen.

Figure 1–1:



Process diagram

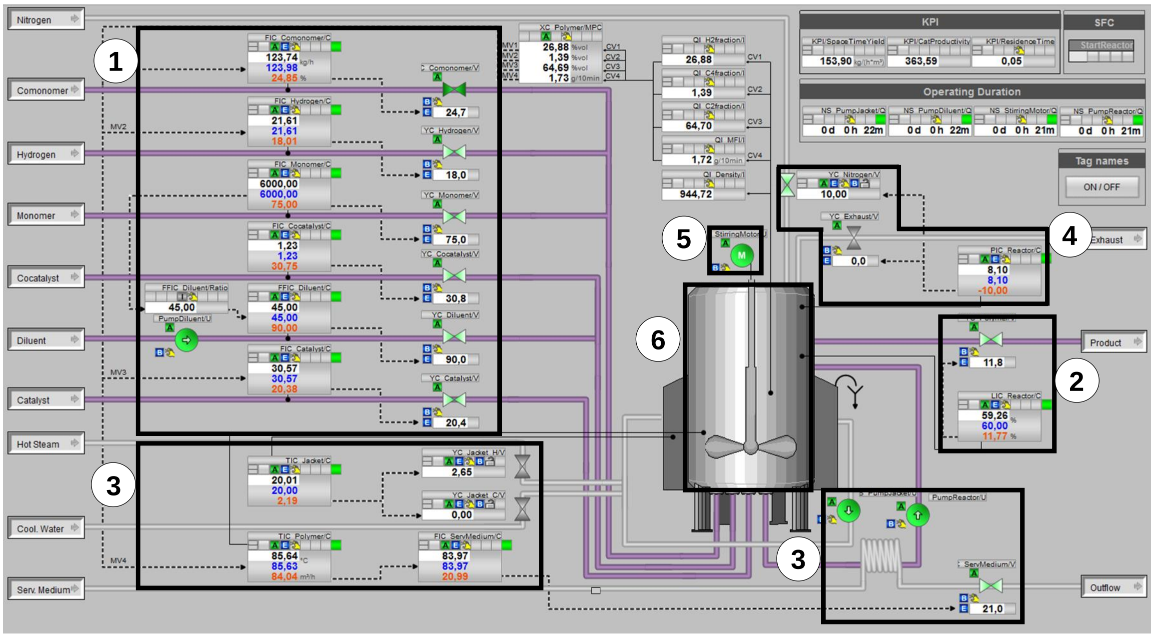
The process picture of a polymerization reactor consists of the following parts:

- A schematic representation of the unit, with input (arranged on the left) and output (arranged on the right) materials
- Graphic modules for controlling the individual components (units)
- SFC for the start and production operation
- Overview of the relevant parameters (Key Performance Indicators) and operating hours display

In the process picture, the operator is provided with an overview of the unit and can carry out the necessary operator intervention.

1.2.4 Description of the individual functions

Figure 1–2



The process picture of a polymerization reactor consists of the following main parts:

1. Inflow of input materials (educts)
2. Level control over product outflow
3. Temperature control (jacket and reactor internal temperature)
4. Pressure control
5. Mixers
6. Polymerization reactor

(1) Inflow of input materials (educts)

The input materials are added to the vessel via the inflow and in the defined flow volume. Different control concepts are used for flow control. These include:

- Ratio control
- Standard control
- Multivariable control for the presetting of educt inflow setpoint values as downstream controls

(2) Level control over product outflow

The flow volume of the outflowing product depends on the fill level of the polymerization reactor and is controlled in a way that the reactor's fill level remains constant. Whenever there's a fill level change (due to a difference between the inflowing and outflowing volumes) the controller reacts to the fill level changes and compensates them by lowering or increasing the outflow volume.

(3) Temperature control (jacket and product temperature)

For the chemical reactions to take place it is required to have the correct temperature of the materials in the reactor (vessel). Due to the temperature dependency of the reaction speed and the exothermic or endothermic chemical reactions, reactor temperature control is a very demanding task. This requirement is fulfilled by using a stirred tank reactor with jacket cooling. The required reaction temperature or reaction environment is preset via the vessel jacket. In order to dissipate the reaction heat of the highly exothermic polymerization, a part of the reactor contents is also pumped through an external heat exchanger. This pumped circulation is necessary, since the heat dissipated from the wall between the reactor and the cooling jacket alone is not sufficient.

Rapid cooling (through an exothermic reaction) of the reaction mass is done by channeling cooling water as a service medium through the heat exchanger, which removes the reaction heat formed by the reaction. In endothermic reactions, the heat of the reaction mass has to be accordingly supplied (not considered in this project).

To reach the preset jacket temperature, the vessel's jacket temperature is controlled with heating steam or cooling water. The vessel jacket influences the temperature inside the reactor with a small lag.

(4) Pressure control

The proper pressure within the vessel and an optimal composition of the gas phase for the reaction in the reactor are required for chemical reactions to take place. To fulfill this requirement, a preset vessel pressure is set via the pressure control and kept constant as much as possible. To increase the pressure, nitrogen is added via a supply line as an inert gas that doesn't participate in the chemical reaction. To reduce the pressure, an outlet valve is opened, thus allowing the gas mixture to escape from the container.

This type of control is called split range control and it can also be used for other tasks, independent from the reactor, where two actuators should controlled by the controller (e.g. temperature control with separate actuators for heating and cooling).

(5) Mixers

The motorized mixer has the task of mixing the added educts or components together and to form a uniform distribution of the material concentration and temperature within the reactor. To avoid damage to the mixer, the mixer must be disabled if the level falls under a certain limit.

(6) Polymerization reactor

Chemical reactions take place in the polymerization reactor. The selection and design of the reactor is done while taking account of procedural contexts, part of which can be very complex.

These include:

- Reaction mixtures that require a special frame size or vessel properties
- Inflow and outflow volumes to determine the reactor size
- Reaction sequence in the necessary environmental requirements (temperature, pressure, mixing)

The concentration of various substances in the reactor and the melt flow index of the polymer are also recorded and used for flow rate and temperature control.

Parameters (KPI: Key Performance Indicators)

The key performance indicators are measured or calculated:

- Dwell time
- Space-time yield
- Catalyst productivity

Operating hours counter

The process picture contains the following operating hours counters:

- Motor of the mixer
- Pump for diluent (educt)
- Pump for cooling/heating medium of the vessel jacket
- Pump for cooling/heating medium of the heat exchanger

1.2.5 Control concept

A multivariable control (MPC) is used to control the concentration of the gaseous materials in the reactor and the product quality (melt flow index of the polymer) by taking over setpoint value specifications for the inflows (comonomer, hydrogen, catalyst) during the process.

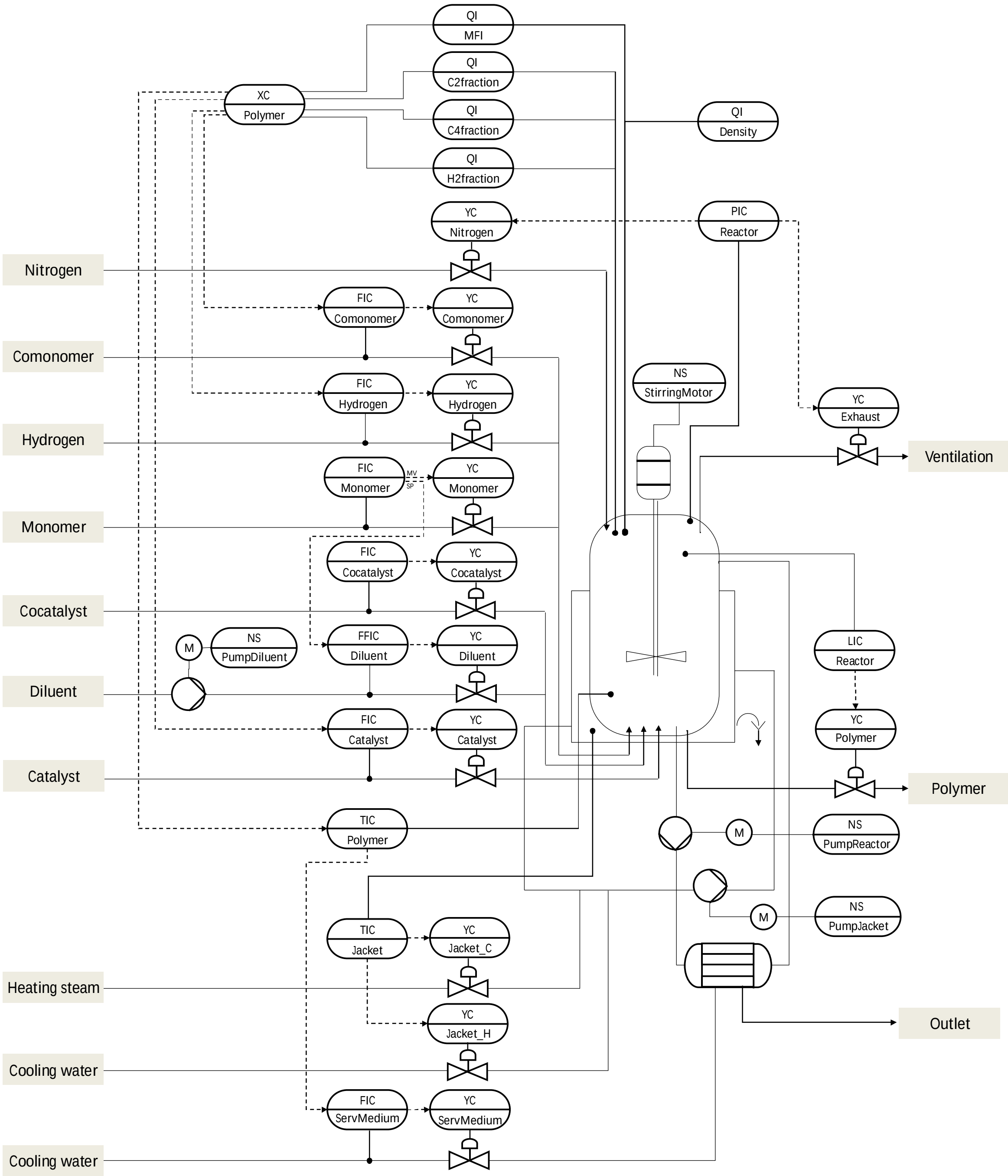
If measurable disturbances occur in the system, and the process is significantly influenced, these can be used for the feedforward control.

For the subordinate controllers, the PID controller "PIDConL" of the APL is employed for the flow rate of the comonomer, the hydrogen and the catalyst. All other controllers are also equipped with PID controllers, however they are designed as standard, split range, cascade or ratio controllers.

1.2.6 Piping and instrumentation diagram

The following figure shows the individual elements of the polymerization reactor in a piping and instrumentation diagramm.

Figure 1–3



1.3 Hardware and software components

1.3.1 Scope

This application applies to

- SIMATIC PCS 7 V8.0 SP1
- SIMATIC PCS 7 V8.1 SP1

1.3.2 Components used

Hardware components

Table 1–1

Component	Note
SIMATIC PCS 7 ES/OS IPC547D W7	For the PCS 7 V8.0 SP1 sample project
SIMATIC PCS 7 ES/OS IPC647D	For the PCS 7 V8.1 SP1 sample project

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 Read Me file of the PCS 7.

Standard software components

Table 1–2

Component	Note
S7-PLCSIM	License is not a part of SIMATIC PCS 7 ES/OS
APG library	License is not a part of SIMATIC PCS 7

Samples files and projects

Table 1–3

Component	Note
84061788_PolyReactor_DOC_en.pdf	This document
84061788_PolyReactor_PCS7V801.zip	PCS 7 V8.0 SP1 example project
84061788_PolyReactor_APG_PCS7V801.zip	PCS 7 V8.0 SP1 example project with APG process pictures
84061788_PolyReactor_APG_PCS7V811.zip	PCS 7 V8.1 SP1 example project with APG process pictures

Note

The PCS 7 example project is based on the PCS 7 Industry Library (IL) and the PCS 7 Advanced Process Library (APL). Whereas the APL is covered by the SIMATIC PCS 7 Engineering license, you must obtain a separate Engineering license and Runtime licenses for IL.

The download contains the block "SimAn", which requires a license. The usage of this block in your configuration environment or in the process mode obligates you to purchase the PCS 7 Industry Library licenses.

Ordering information can be found under the following entry ID:

- 104206476 (PCS 7 Advanced Process Graphics V8.1)
- 74789158 (PCS 7 Advanced Process Graphics V8.0)
- 104206371 (PCS 7 Industry Library V8.1)
- 68376061 (PCS 7 Industry Library V8.0)

2 Basic principles

2.1 Polymerization

Polymerization is a chemical reaction in which the same or different molecules (also called monomers) combine to form a chain, the so called polymers.
The reaction is initiated by radicals. The unsaturated monomers attach themselves to the chain until it has reached the desired length and possibly also network.
The catalysts used are mostly correspondingly targeted at the reaction control.

The following educts are typically used for the production of polymers: Monomers (in the example of ethane: C_2), comonomers (in the example of butane: C_4), hydrogen (H_2 all gaseous) as well as the catalyst and cocatalyst (solids).

Synthetic polymers based on carbon:

- Polyethylene (PE)
- Polypropylene (PP)
- Polyketone (PK)
- Polyvinyl chloride (PVC)

Synthetic polymers with other bases:

- Silicones, particularly poly(organo)siloxanes
- Melamine resin

Biopolymers:

- Proteins such as enzymes, hair, silk,
- DNA (the genetic material)
- RNA
- Carbohydrates such as cellulose, wood, paper, starch, chitin
- Polyhydroxyalkanoates, the biopolyester as an energy and carbon storage of bacteria

2.2 Melt flow index (MFI, MFR)

The melt flow index (MFI = Melt Flow Index, or MFR = Melt Flow Rate) describes the fluidity (viscosity) of a material/materials, such as polymer melt and is expressed in weight per 10 minutes (g/10 min). This flow behavior applies to certain pressure and temperature conditions. The melt flow index is related to the length of the polymer chains and is thus indirectly a measure for other polymer properties such as density and hardness.

A fixed MFI of the finished good is usually preset as a specification for a particular polymer. Excessive deviation means an insufficient quality.

Alternatively, it is also possible to define a melt volume-flow rate (MVR = Melt Volume Rate, MVI = Melt Volume Index). This is expressed in volume per 10 minutes (cm^3/10 min).

3 Design and principle of operation

3.1 Project structure

3.1.1 CFC structure

A uniform naming convention is used for identifying the measurement points, whereby the function has been named according to the European standard EN 62424. The following figure shows the composition of a measurement point name:

Figure 3–1

TIC_Jacket

Function — Designation

T = temperature (first letter)
I = indication (subsequent letter)
C = control (subsequent letter)

The following table contains all letters used in the application their meanings:

Table 3-1

First letter	Meaning
F	Flow
L	Level
M	Moisture
N	Motor
P	Pressure
Q	Amount, quantity or quality
C	Speed (velocity, rotational speed, frequency)
T	Temperature
X	Freely selectable first letter
Y	Control valve

Table 3-2

Subsequent letter	Meaning
C	Control
F	Fraction
I	Indication
C	Binary control function or switching function (not safety-oriented) ("switching")

3.1.2 Plant view

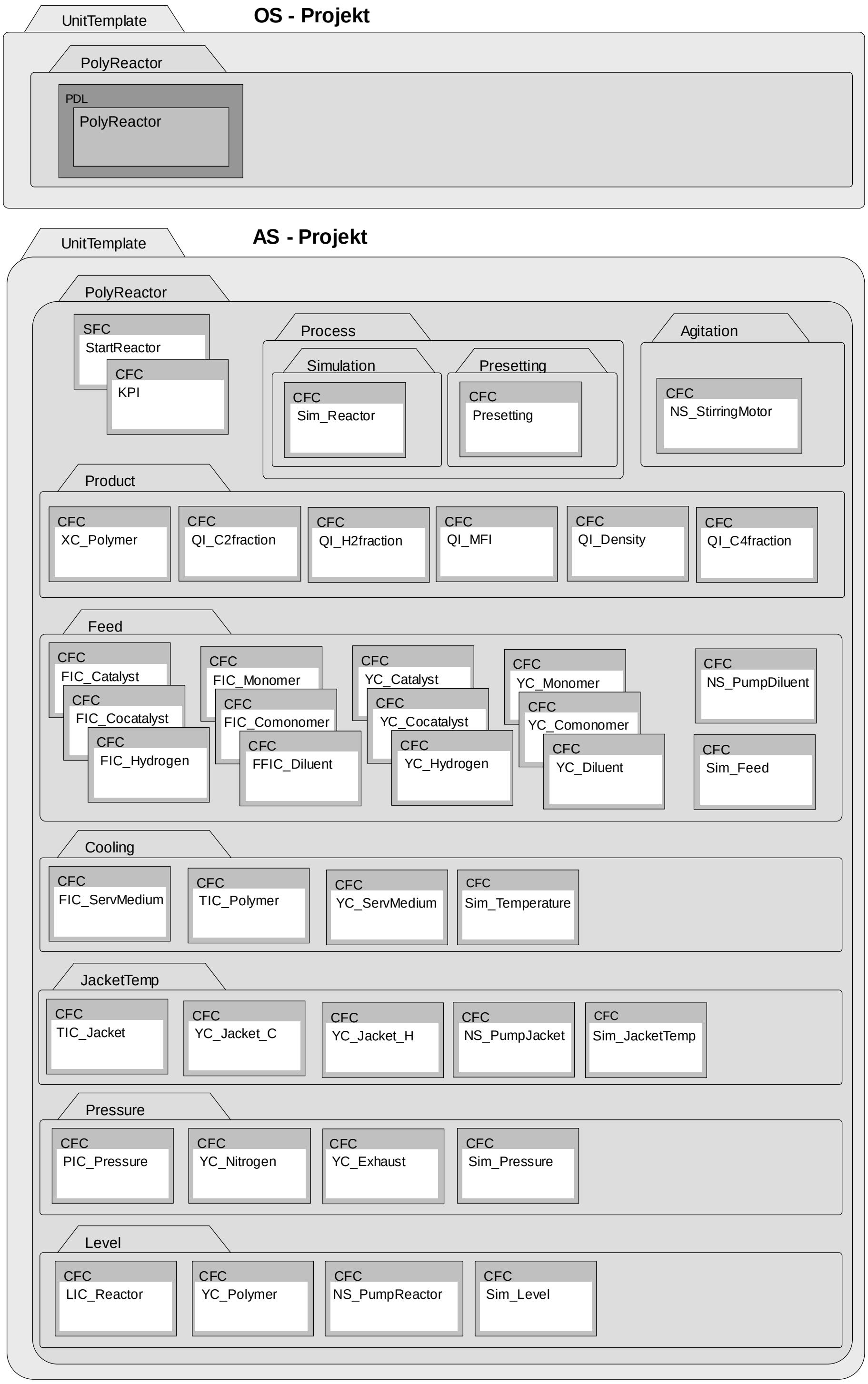
The unit template "Polymerization Reactor" is implemented in the plant view in two hierarchy levels.

In the AS project, the first hierarchy level is empty and in the subordinate hierarchy level there is only respectively one hierarchy folder, with the necessary CFC charts and the associated process simulation ("Sim_*" charts), for each technical function (functional unit) of the polymerization reactor. The simulation can be removed for use in a real plant.

The first hierarchy level of the OS project is also empty. The process picture "PolyReactor.pdl" of the polymerization reactor is located in the subordinate hierarchy folder.

The following figure depicts the PCS 7 multiproject structure.

Figure 3–2



3.2 Equipment modules and process tags

The unit template "Polymerization Reactor" consists of pre-made equipment modules and additional CFC charts, e.g. for process simulation. In a PCS 7 project, all process tags – such as of the equipment modules – are based on process tag types from the master data library. You will find the application description "Equipment Modules for PCS 7 using the example of the Chemical Industry" and the example projects with the individual equipment modules and process tag types under the entry ID: 53843373.

The application example contains the following elements:

- Educt addition (Feed): Feed control of the individual educts and catalysts
- Level control (Level): Level control of the discharge
- Jacket temperature control (JacketTemp): Control of the jacket temperature
- Product temperature control (Cooling): Control of the reactor internal temperature
- Pressure control (Pressure): Control of the tank pressure
- Mixing (Agitation): Mixing of the product
- Material concentrations and melt flow index (polymer)
- Sequencer (SFC) for starting up the polymerization reactor
- Overarching process simulation (Simulation)
- Process parameters (KPI)

In the following sections you will find the setup of the specific equipment modules as well as the extension and modifications made vis-à-vis the original equipment modules measurement point types. In addition, the SFC for starting up the polymerization reactor is documented.

Note

All necessary descriptions, configurations and procedures pertaining to the reference versions can be found in the documentation under the entry ID: 53843373. You will find the information on the specific equipment modules in Chapter 5 "Equipment Modules" and on the measurement point types in Chapter 4 "Individual Control Level".

3.3 Educt addition (feed)

The total inflow is composed of various solid or gaseous educts. The inflow control is performed by a multivariable controller process tag (material concentration), a ratio control and a standard flow control with fixed setpoint value specifications through the step sequencer.

Design

Inflow of the cocatalyst via flow control

The flow control (PID control) for the cocatalyst gets its setpoint value from the SFC. As with the monomer, the cocatalyst receives a fixed setpoint value for the production.

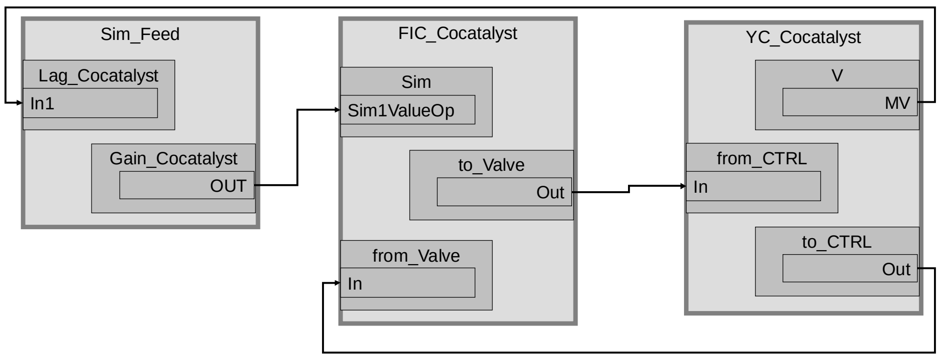
The following table provides you with an overview of the elements and measurement point types used.

Table 3–3

Name	Process tag type	Description
FIC_Cocatalyst	"CTRL_Std4Valve"	Flow control of the cocatalyst, setpoint value from the SFC
YC_Cocatalyst	"Val_An_Afb1"	Control valve for "FIC_Cocatalyst"

In the following figure, the structure with the cross-chart interconnection is depicted in simplified form.

Figure 3–3



Inflow via ratio control

Two inflows are realized with the "Ratio-Control" technical function. This includes the main monomer educt to which the other diluent educt is added in a specified (stoichiometrically meaningful) value.

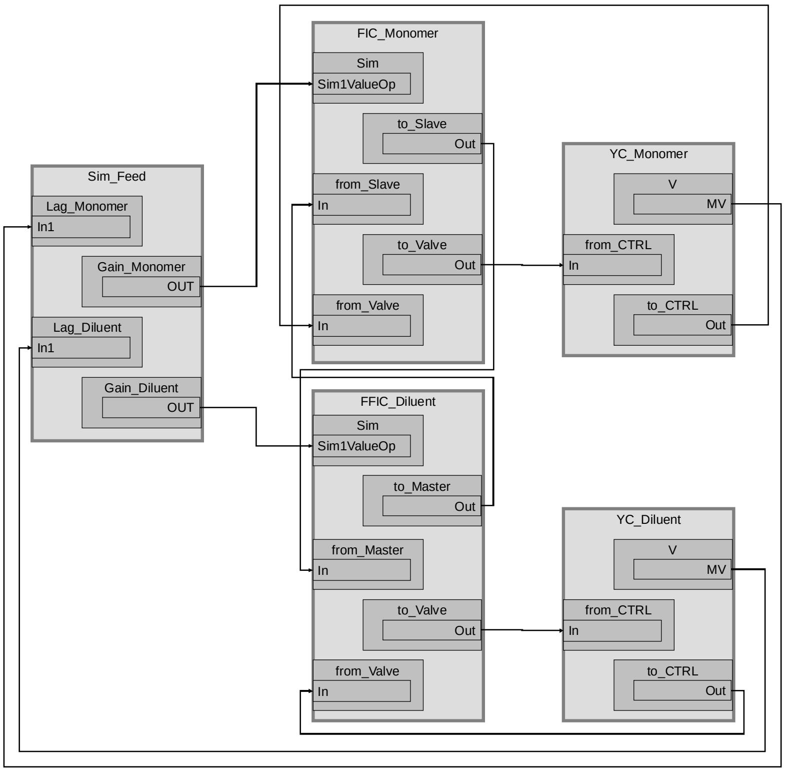
The following table provides you with an overview of the elements.

Table 3–4

Name	Technical function / process tag type	Description
FIC_Monomer	"Ratio-Control"	Flow control of the main components
YC_Monomer	"Ratio-Control"	Control valve for "FIC_Monomer"
FFIC_Diluent	"Ratio-Control"	Ratio control of the secondary component in relation to the main component
YC_Diluent	"Ratio-Control"	Control valve for "FFIC_Diluent"
NS_PumpDiluent	"MOT_1sp_1fb_1cm__Std"	Pump for diluent

In the following figure, the structure with the cross-chart interconnection is depicted in simplified form.

Figure 3–4



Inflow via multivariable control

The multivariable control "XC_Polymer" controls the reaction conditions (concentration of gases in the reactor) as well as the quality of the polymers. To achieve this, the controller detects the concentrations of the components C_2, C_4 and H_2 and delivers its manipulated variables as external setpoint values to the slave controllers "FIC_Catalyst" "FIC_Hydrogen" and "FIC_Comonomer". The multivariable controller also gives a setpoint value for the reactor temperature, see section 3.9.

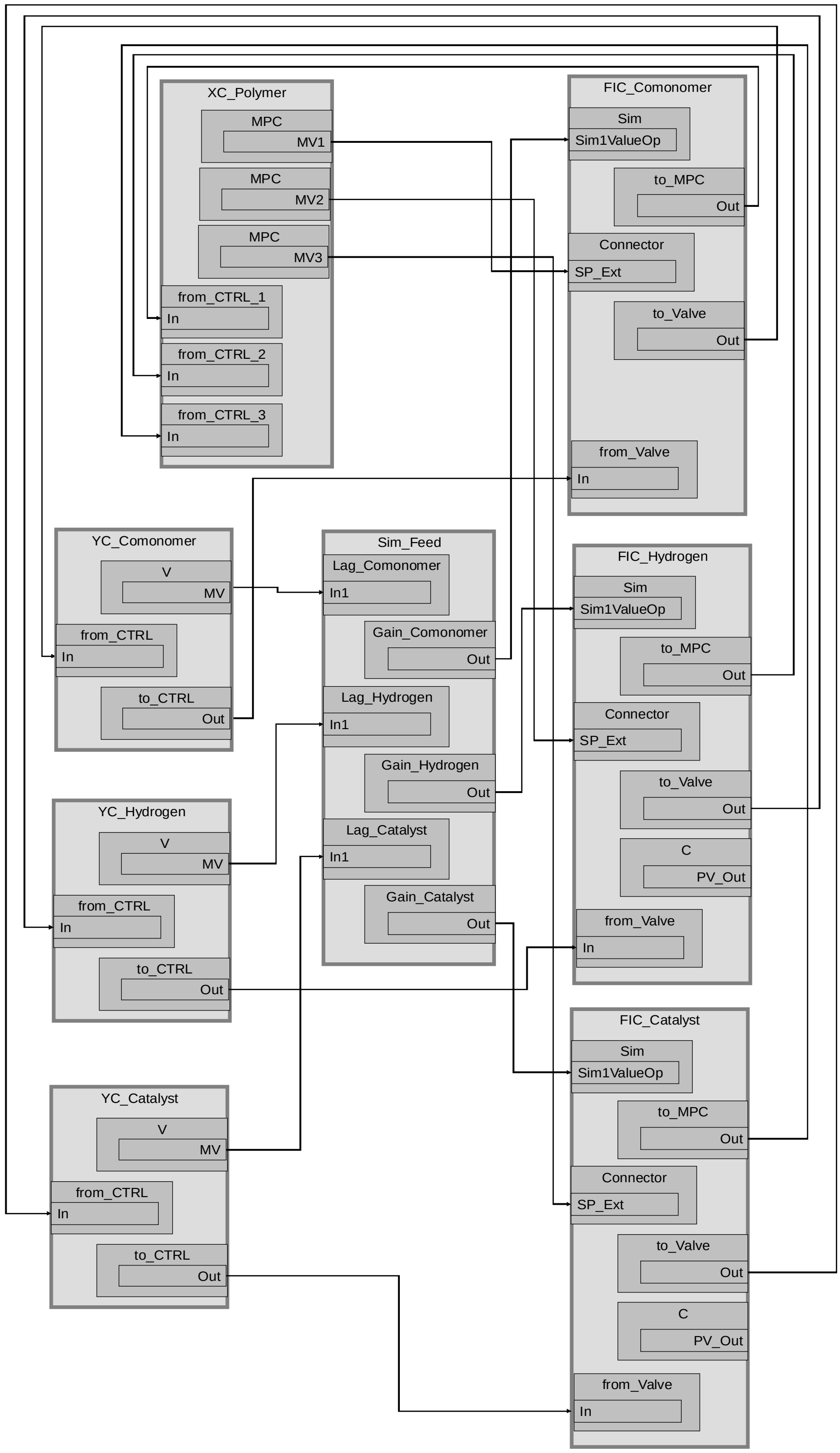
The following table provides you with an overview of the elements.

Table 3–5

Name	Process tag type	Description
FIC_Catalyst	"CTRL_Std4MPC"	Flow controller for catalyst, actuated by the MPC
YC_Catalyst	"Val_An_Afb1"	Control valve for "FIC_Catalyst"
FIC_Hydrogen	"CTRL_Std4MPC"	Flow controller for hydrogen, actuated by the MPC
YC_Hydrogen	"Val_An_Afb1"	Control valve for "FIC_Hydrogen"
FIC_Comonomer	"CTRL_Std4MPC"	Flow controller for comonomer, actuated by the MPC
YC_Comonomer	"Val_An_Afb1"	Control valve for "FIC_Comonomer"

In the following figure, the structure of the flow controller including all the cross-chart interconnection is depicted in simplified form.

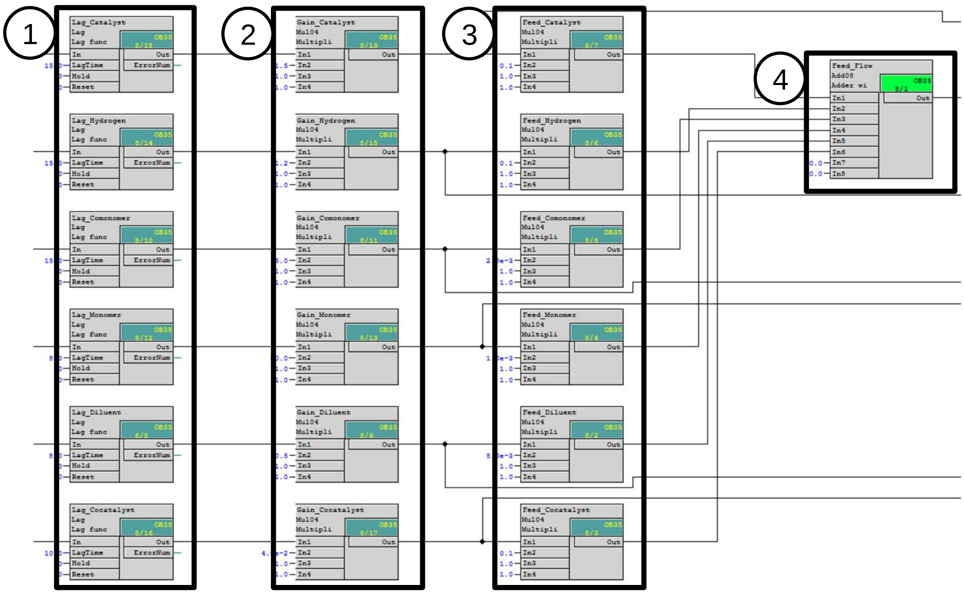
Figure 3–5



Simulation

The simulation chart "Sim_Feed" provides simulations of the time lag, the process gain and the flow scaling for all inflows.

Figure 3–6



1. Time lag in seconds "Lag_xxxxx", which is caused by the inertia of the actuator and also by the time constant of the flow sensor (incl. low-pass filter in the measuring instrument).
2. The "Gain_xxxx" factor defines the process gain.
3. The "Feed_xxxx" factor defines the scaling or the flow volume of the educts.
4. Summation of all inflows.

Parameter assignment

FIC_Catalyst

The following table shows the configuration of the instance from "CTRL_Std4MPC".

Table 3-6

Module	Connection	Value	Usage
C	Gain	13.5	Controller gain
C	TI	1.8	Controller lag
C	SP_InHiLim	50.0	Maximum value of the internal setpoint
C	PropFacSP	0.5	P-action in feedback loop
to_MPC	Out		Interconnection for the multivariable controller (XC_Polymer\from_CTRL_3.In)
to_Valve	Out		Interconnection for the valve (control) (YC_Catalyst\from_CTRL.In)
from_Valve	In		Interconnection for the valve (status) (YC_Catalyst\to_CTRL.Out)
Sim	Sim1ActOp.Value	1	Activate the simulation values
Sim	Sim1ValueOp		Interconnection for the simulated process value

Module	Connection	Value	Usage
			(Sim_Feed\Gain_Catalyst.Out)
PV	Scale	150.0	Maximum value of the process value
PV	PV_InUnit	1324	Unit of the process value (kg/h)

FIC_Hydrogen

The following table shows the configuration of the instance from "CTRL_Std4MPC".
Table 3-7

Module	Connection	Value	Usage
C	Gain	22.5	Controller gain
C	TI	1.4	Controller lag
C	SP_InHiLim	50.0	Maximum value of the internal setpoint
C	PropFacSP	0.5	P-action in feedback loop
to_MPC	Out		Interconnection for the multivariable controller (XC_Polymer\from_CTRL_2.In)
to_Valve	Out		Interconnection for the valve (control) (YC_Hydrogen\from_CTRL.In)
from_Valve	In		Interconnection for the valve (status) (YC_Hydrogen\to_CTRL.Out)
Sim	Sim1ActOp.Value	1	Activate the simulation values
Sim	Sim1ValueOp		Interconnection for the simulated process value (Sim_Feed\Gain_Hydrogen.Out)
PV	Scale	120.0	Maximum value of the process value
PV	PV_InUnit	1349	Unit of the process value (m^3/h)

FIC_Comonomer

The following table shows the configuration of the instance from "CTRL_Std4MPC".
Table 3-8

Module	Connection	Value	Usage
C	Gain	5.29	Controller gain
C	TI	5.372	Controller lag
C	SP_InHiLim	180.0	Maximum value of the internal setpoint
C	PropFacSP	0.5	P-action in feedback loop
to_MPC	Out		Interconnection for the multivariable controller (XC_Polymer\from_CTRL_1.In)
to_Valve	Out		Interconnection for the valve (control) (YC_Comonomer\from_CTRL.In)
from_Valve	In		Interconnection for the valve (status) (YC_Comonomer\to_CTRL.Out)
Sim	Sim1ActOp.Value	1	Activate the simulation values
Sim	Sim1ValueOp		Interconnection for the simulated process value (Sim_Feed\Gain_Comonomer.Out)

Module	Connection	Value	Usage
PV	Scale	500.0	Maximum value of the process value
PV	PV_InUnit	1324	Unit of the process value (kg/h)

FIC_Monomer

The process tag has the following different configuration when compared to the ratio control.

Table 3-9

Module	Connection	Value	Usage
C	Gain	0.618	Controller gain
C	TI	7.211	Controller lag
C	SP_InHiLim	8000.0	Maximum value of the internal setpoint
Sim	Sim1ValueOp		Interconnection for the simulated process value (Sim_Feed\Gain_Monomer.Out)
PV	Scale	8000.0	Maximum value of the process value
PV	PV_InUnit	1324	Unit of the process value (kg/h)

FFIC_Diluent

The process tag has the following different configuration when compared to the ratio control.

Table 3-10

Module	Connection	Value	Usage
C	Gain	0.2	Controller gain
C	TI	1.0	Controller lag
C	SP_InHiLim	150.0	Maximum value of the internal setpoint
Ratio	RatioInt	0.01	Internal ratio value
Ratio	RatioExt	0.007105	External ratio value
Ratio	RatHiLim	1.0	Upper ratio value
Ratio	RatioOpScale	1.0	Scaling of the ratio value for the operator
Ratio	OutHiLim	150.0	Upper limit value for the output value
Sim	Sim1ValueOp		Interconnection for the simulated process value (Sim_Feed\Gain_Diluent.Out)
PV	Scale	150.0	Maximum value of the process value
PV	PV_InUnit	1349	Unit of the process value (m^3/h)

FIC_Cocatalyst

The following table shows the configuration of the instance from "CTRL_Std4Valve".

Table 3-11

Module	Connection	Value	Usage
C	Gain	23.0	Controller gain
C	TI	9.0	Controller lag
C	SP_InHiLim	4.0	Maximum value of the internal setpoint
to_Valve	Out		Interconnection for the valve (control) (YC_Cocatalyst\from_CTRL.In)
from_Valve	In		Interconnection for the valve (status) (YC_Cocatalyst\to_CTRL.Out)
Sim	Sim1ActOp.Value	1	Activate the simulation values
Sim	Sim1ValueOp		Interconnection for the simulated process value (Sim_Feed\Gain_Cocatalyst.Out)
PV	Scale	4.0	Maximum value of the process value
PV	PV_InUnit	1324	Unit of the process value (kg/h)

YC_Catalyst

The valve measurement point "YC_Catalyst" controls the flow volume (opening of the feed input) to the vessel. The measurement point contains communications modules for data exchange (control signals and control commands) with the controller measurement point.

The valve module "V" contains an external manipulated variable (through a communications module) from the controller measurement point. In a simulation environment, both channel modules in chart partition "B" (Rbk and MV) receive the same value (manipulated variable of the valve module (chart partition "A", sheet 1)) through the primary simulation module, i.e. a lag between valve actuation and valve movement is not simulated.

The following table shows the configuration of the instance from "Val_An_Afb1".

Table 3-12

Module	Connection	Value	Usage
V	MV		Interconnection for the simulation (Sim_Feed\Lag_Catalyst.In)
V	ER_AH_En (not visible)	0	Switching off the alarm message with maximum valve opening
V	ER_AL_En (not visible)	0	Switching off the alarm message with minimum valve opening
from_CTRL	In		Interconnection for the controller (FIC_Catalyst\to_Valve.Out)
to_CTRL	Out		Interconnection for the controller (FIC_Catalyst\from_Valve.In)
Sim	Sim1ActOp.Value	1	Activate simulation of the read-back value
Sim	Sim1ValueOp		Interconnected with the simulation of the read-back value from the valve (YC_Catalyst\V.MV)

Module	Connection	Value	Usage
Sim	Sim2ActOp.Value	1	Activate simulation of the manipulated variable
Sim	Sim2ValueOp		Interconnection with the simulation of the manipulated variable from the valve (YC_Catalyst\V.MV)

YC_Hydrogen

The valve measurement point "YC_Hydrogen" controls the flow volume (opening of the feed input) to the vessel. The measurement point contains communications modules for data exchange (control signals and control commands) with the controller measurement point.

The valve module "V" contains an external manipulated variable (through a communications module) from the controller measurement point. In a simulation environment, both channel modules in chart partition "B" (Rbk and MV) receive the same value (manipulated variable of the valve module (chart partition "A", sheet 1)) through the primary simulation module, i.e. a lag between valve actuation and valve movement is not simulated.

The following table shows the configuration of the instance from "Val_An_Afb1".

Table 3-13

Module	Connection	Value	Usage
V	MV		Interconnection for the simulation (Sim_Feed\Lag_Hydrogen.In)
V	ER_AH_En (not visible)	0	Switching off the alarm message with maximum valve opening
V	ER_AL_En (not visible)	0	Switching off the alarm message with minimum valve opening
from_CTRL	In		Interconnection for the controller (FIC_Hydrogen\to_Valve.Out)
to_CTRL	Out		Interconnection for the controller (FIC_Hydrogen\from_Valve.In)
Sim	Sim1ActOp.Value	1	Activate simulation of the read-back value
Sim	Sim1ValueOp		Interconnected with the simulation of the read-back value from the valve (YC_Hydrogen\V.MV)
Sim	Sim2ActOp.Value	1	Activate simulation of the manipulated variable
Sim	Sim2ValueOp		Interconnection with the simulation of the manipulated variable from the valve (YC_Hydrogen\V.MV)

YC_Comonomer

The valve measurement point "YC_Comonomer" controls the flow volume (opening of the feed input) to the vessel. The measurement point contains communications modules for data exchange (control signals and control commands) with the controller measurement point.

The valve module "V" contains an external manipulated variable (through a communications module) from the controller measurement point. In a simulation environment, both channel modules in chart partition "B" (Rbk and MV) receive the same value (manipulated variable of the valve module (chart partition "A", sheet 1)) through the primary simulation module, i.e. a lag between valve actuation and valve movement is not simulated.

The following table shows the configuration of the instance from "Val_An_Afb1".

Table 3-14

Module	Connection	Value	Usage
V	MV		Interconnection for the simulation (Sim_Feed\Lag_Comonomer.In)
V	ER_AH_En (not visible)	0	Switching off the alarm message with maximum valve opening
V	ER_AL_En (not visible)	0	Switching off the alarm message with minimum valve opening
from_CTRL	In		Interconnection for the controller (FIC_Comonomer\to_Valve.Out)
to_CTRL	Out		Interconnection for the controller (FIC_Comonomer\from_Valve.In)
Sim	Sim1ActOp.Value	1	Activate simulation of the read-back value
Sim	Sim1ValueOp		Interconnected with the simulation of the read-back value from the valve (YC_Comonomer\V.MV)
Sim	Sim2ActOp.Value	1	Activate simulation of the manipulated variable
Sim	Sim2ValueOp		Interconnection with the simulation of the manipulated variable from the valve (YC_Comonomer\V.MV)

YC_Monomer

The process tag has the following different configuration when compared to the ratio control.

Table 3-15

Module	Connection	Value	Usage
V	MV		Interconnection for the simulation (Sim_Feed\Lag_Monomer.In)
V	ER_AH_En (not visible)	0	Switching off the alarm message with maximum valve opening
V	ER_AL_En (not visible)	0	Switching off the alarm message with minimum valve opening

YC_Cocatalyst

The valve measurement point "YC_Cocatalyst" controls the flow volume (opening of the feed input) to the vessel. The measurement point contains communications modules for data exchange (control signals and control commands) with the controller measurement point.

The valve module "V" contains an external manipulated variable (through a communications module) from the controller measurement point. In a simulation environment, both channel modules in chart partition "B" (Rbk and MV) receive the same value (manipulated variable of the valve module (chart partition "A", sheet 1)) through the primary simulation module, i.e. a lag between valve actuation and valve movement is not simulated.

The following table shows the configuration of the instance from "Val_An_Afb1".

Table 3-16

Module	Connection	Value	Usage
V	MV		Interconnection for the simulation (Sim_Feed\Lag_Cocatalyst.In)
V	ER_AH_En (not visible)	0	Switching off the alarm message with maximum valve opening
V	ER_AL_En (not visible)	0	Switching off the alarm message with minimum valve opening
from_CTRL	In		Interconnection for the controller (FIC_Cocatalyst\to_Valve.Out)
to_CTRL	Out		Interconnection for the controller (FIC_Cocatalyst\from_Valve.In)
Sim	Sim1ActOp.Value	1	Activate simulation of the read-back value
Sim	Sim1ValueOp		Interconnected with the simulation of the read-back value from the valve (YC_Cocatalyst\V.MV)
Sim	Sim2ActOp.Value	1	Activate simulation of the manipulated variable
Sim	Sim2ValueOp		Interconnection with the simulation of the manipulated variable from the valve (YC_Cocatalyst\V.MV)

YC_Diluent

The valve measurement point "YC_Diluent" controls the flow volume (opening of the feed input) to the vessel. The measurement point contains communications modules for data exchange (control signals and control commands) with the controller measurement point.

The valve module "V" contains an external manipulated variable (through a communications module) from the controller measurement point. In a simulation environment, both channel modules in chart partition "B" (Rbk and MV) receive the same value (manipulated variable of the valve module (chart partition "A", sheet 1)) through the primary simulation module, i.e. a lag between valve actuation and valve movement is not simulated.

The valve measurement point is additionally connected to the "NS-PumpDiluent" pump. As soon as the valve opens, the interlock is released, thus allowing the pump to be started.

The following table shows the configuration of the instance from "Val_An_Afb1".

Table 3-17

Module	Connection	Value	Usage
V	MV		Interconnection for the simulation and pump (Sim_Feed\Lag_Cocatalyst.In) (NS_PumpDiluent\OperatingRange.In)
V	ER_AH_En (not visible)	0	Switching off the alarm message with maximum valve opening

Module	Connection	Value	Usage
V	ER_AL_En (not visible)	0	Switching off the alarm message with minimum valve opening
from_CTRL	In		Interconnection for the controller (FIC_Cocatalyst\to_Valve.Out)
to_CTRL	Out		Interconnection for the controller (FIC_Cocatalyst\from_Valve.In)
Sim	Sim1ActOp.Value	1	Activate simulation of the read-back value
Sim	Sim1ValueOp		Interconnected with the simulation of the read-back value from the valve (YC_Cocatalyst\V.MV)
Sim	Sim2ActOp.Value	1	Activate simulation of the manipulated variable
Sim	Sim2ValueOp		Interconnection with the simulation of the manipulated variable from the valve (YC_Cocatalyst\V.MV)

NS_PumpDiluent

Pump control is done in CFC "NS_PumpDiluent", based on the process tag type "MOT_1sp_1fb_1cm__Std". The process tag type forms part of the master data library.

The pump is controlled via SFC and is driven as soon as the downstream control valve "YC_Diluent" opens (MV ≥ 1%). When the control valve is closed, the interlock of the pump is active.

3.4 Level control (Level)

Level control is done via the product discharge and is realized with the "Level-Control" equipment module. The level calculation is performed in the simulation chart. The reactor serves as a buffer, enabling a product discharge which is as continuous as possible. For this purpose, a dead band is defined in the controller CFC.

Design

The PID controller detects the fill level of the simulation chart and controls the discharge flow volume depending on the predetermined fill level. If the fill level comes below 30% of the reactor, the interlocking of the mixer is activated (mixer "Agitation"). The following table provides you with an overview of the elements.

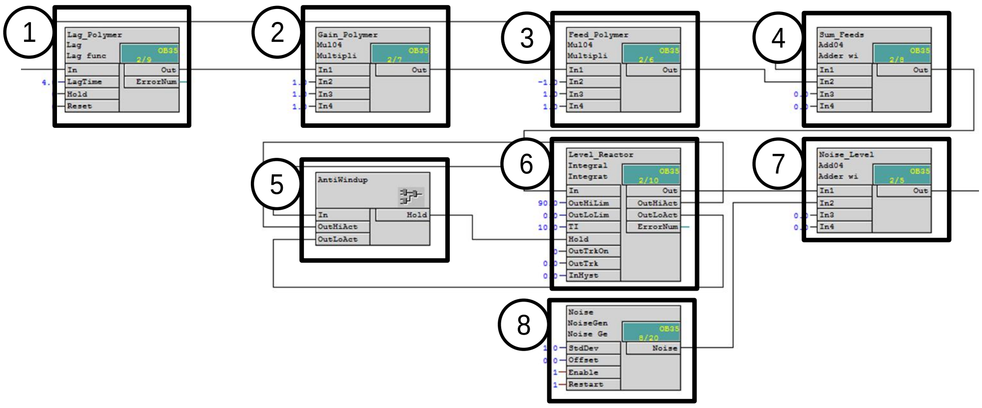
Table 3-18

Name	Technical function / process tag type	Description
LIC_Reactor	"Level-Control"	Level control
YC_Polymer	"Level-Control"	Control valve for the product discharge
NS_PumpReactor	"MOT_1sp_1fb_1cm__Std"	Pump to feed the reactor contents

Simulation "Sim_Level"

In the "Sim_Level" simulation chart, the fill level is calculated on the basis of the difference between all inflows and the outflow.

Figure 3–7



1. Lag time of 4 seconds, which is caused by the inertia of the actuator, and the time constant of the flow sensor.
2. The gain factor for the simulation of the process gain.
3. The scaling factor (negative inflow) for the polymer outflow volume.
4. Summation of all inflows including discharge.
5. Limiting the fill level by stopping the integration
6. Integration of the inflow sum
7. Fill level value with added noise signal
8. White noise signal as a simulation for measurement noise.

Parameter assignment

LIC_Reactor

The process tag has the following different configuration when compared to the "Level-Control" technical function.

Table 3-19

Module	Connection	Value	Usage
C	Gain	1.5	Controller gain
C	TI	100.0	Controller lag
C	DeadBand	5.0	Deadband width
C	SP_InHiLim	100.0	Upper limit of the inner setpoint value
C	PV_Out		Interconnection for (Agitation\\NS_StirringMotor\OperatingRange.In) (NS_PumpReactor\OperatingRange.In)
Sim	Sim1ValueOp		Interconnection for the simulated process value (Sim_Level\Noise_Level.Out)
PV	Scale	100.0	Maximum value of the process value
PV	PV_InUnit	1342	Process value unit in %

YC_Polymer

The process tag has the following different configuration when compared to the "Level-Control" technical function.

Table 3-20

Module	Connection	Value	Usage
V	MV		Interconnection for the simulation (Sim_Level\Lag_Polymer.In)

NS_PumpReactor

Pump control is done in CFC "NS_PumpReactor", based on the "MOT_1sp_1fb_1cm__Std" process tag type. The process tag type forms part of the master data library.

The pump is controlled via SFC and is driven as soon as the fill level increases (fill level > 0%). When the reactor is empty, the interlock of the pump is active.

3.5 Jacket temperature control (JacketTemp)

The jacket temperature control realized with the "Split–Range–Temperature" technical function provides the basis for an appropriate reaction environment. The "MOT_1sp_1fb_1cm__Std" process tag type is additionally used for the pumped circulation of the jacket fluid. The temperature calculation takes place in the simulation chart.

Design

The PID controller detects the jacket temperature and increases or lowers it according to the SFC temperature specification through the heating steam or cooling water service media.

The following table provides you with an overview of all elements.

Table 3–21

Name	Technical function / process tag type	Description
TIC_Jacket	"Split–Range–Temperature"	Slave controller for the split-range control with one controller output and two actuators
YC_Jacket_C	"Split–Range–Temperature"	Actuator for heating steam
YC_Jacket_H	"Split–Range–Temperature"	Control valve for the cooling water
NS_PumpJacket	"MOT_1sp_1fb_1cm__Std"	Pump (e.g. flow pump) for the continuous pumped circulation of the jacket fluid

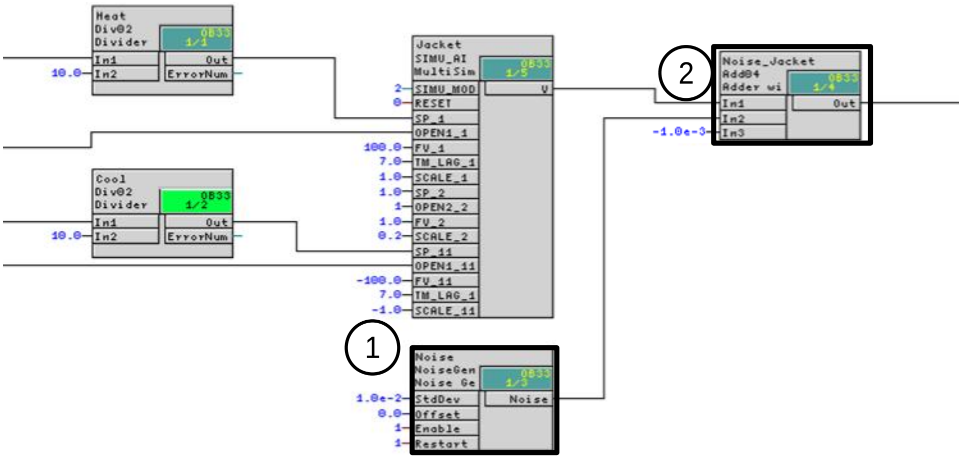
Note The display process tag and the controller process tag of the "TIC_Temp" master controller of the "Split–Range–Temperature" equipment module are not needed in this case and are therefore not part of the solution. For this reason, the communication blocks "to_Master" and "from_Master" have been deleted in the "TIC_Jacket" process tag. The missing process tags and interconnections have no effect on the functionality and are not described separately.

Sim_JacketTemp simulation

The "Sim_JacketTemp" CFC chart (part of the "Split–Range–Temperature" technical function) was reduced to the simulation part of the heat exchanger ("TempLevel" block) and contains an additional noise signal.

The figure below shows the structure and sequence of the simulation.

Figure 3–8



1. Generating a noise signal (process behavior)
2. Adding the noise signal to the temperature value of the reactor jacket and environment-related drop in temperature (0.001 degree Celsius)

NS_PumpJacket

Pump control is done in CFC "NS_PumpJacket", based on the "MOT_1sp_1fb_1cm__Std" process tag type. The process tag type forms part of the master data library.

Note You will find the information on the description, configuration and procedure of the process tag type "MOT_1sp_1fb_1cm__Std" in chapter 4 "Individual Control Level" of the documentation under the Entry ID: 53843373.

Note The interlocking of the pump can be carried out (configured) for the following cases:
- if the controller is turned off
- a leak is detected in the jacket

Parameter assignment

The temperature control via the reactor jacket is configured for autonomous operation. Since no effects of other system components are simulated in this example and the controller has a fast response, no changes shall be carried out for this example.

3.6 Product temperature control (Cooling)

The temperature control is used for the heat dissipation of the reaction heat. To counteract the resulting reaction heat, a portion of the contents of the reactor is continuously pumped through an external heat exchanger and cooled down with a service medium, such as cooling water. The temperature control is realized with the "Temperature-Flow Cascade" technical function.

Design

The master controller of the motor staging gets the setpoint temperature of the polymer melt defined as an external setpoint value from the "XC_Polymer" multivariable controller. The master controller "TIC_Polymer" gives the flow volume of the service medium to the "FIC_ServMedium" slave controller as an external setpoint value.

The following table provides you with an overview of all elements.

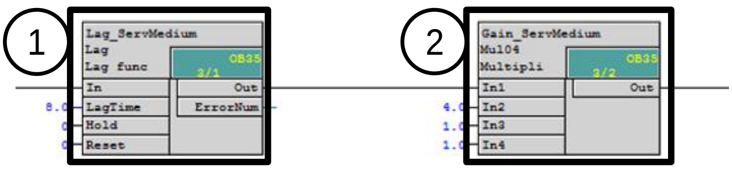
Table 3-22

Name	Technical Function	Description
TIC_Polymer	"Temperature-Flow-Cascade"	Master controller to control the temperature
FIC_ServMedium	"Temperature-Flow-Cascade"	Slave controller for the flow control
YC_ServMedium	"Temperature-Flow-Cascade"	Control valve for the coolant

Simulation

The flow volume of the cooling water to the heat exchanger is simulated in the simulation chart. In the "Sim_Reactor" process simulation, the change in temperature (temperature increase due to the chemical process and the cooling down through the Service medium) is simulated again.

Figure 3–9



1. Lag time of 4 seconds, which is caused by the inertia of the actuator as well as by the time constant of the flow sensor.
2. The gain factor for the simulation of the process gain.

Parameter assignment

TIC_Polymer

The process tag has an additional "to_MPC" block which serves as a connection to the "XC_Polymer" multivariable control measuring point. The manipulated variable of the multivariable controller measurement point is used as an external setpoint value for the control.

The "to_MPC" ("ComStruIn") block passes control commands from the PID controller ("SP_InHiOut", "SP_InLoOut", "PV_Out", "CascaCut", "PV_UnitOut") to the MPC controller.

The process tag has the following different configuration when compared to the "Temperature-Flow-Cascade" technical function.

Table 3-23

Module	Connection	Value	Usage
C	NegGain	1	Negative controller gain
C	Gain	2.0	Controller gain
C	TI	20.0	Controller lag
C	SP_InHiLim	90.0	Maximum value of the internal setpoint
Connector	SP_Ext		Manipulated variable of the multivariable controller (XC_Polymer\ConnMPC.MV4Out)
ComStruIn			Entered as "to_MPC" for transmitting control signals to the multivariable controller measurement point
to_MPC	Out		Interconnection of the multivariable measuring point (XC_Polymer\from_CTRL_4.In)
to_MPC	ReStru1		Interconnection to the maximum value of the internal setpoint (TIC_Polymer\C.SP_InHiOut)
to_MPC	ReStru2		Interconnection to the maximum value of the internal setpoint (TIC_Polymer\C.SP_InLoOut)
to_MPC	ReStru3		Interconnection to the process value (TIC_Polymer\C.PV_Out)
to_MPC	BoStru1		Interconnection to the cascade signal (TIC_Polymer\C.CascaCut)
to_MPC	Int1		Interconnection to the process value unit (TIC_Polymer\C.PV_UnitOut)
Sim	Sim1ValueOp		Interconnection for the simulated process value (Process\Simulation\Sim_Reactor\Temp_Polymer.Out)
PV	Scale	120.0	Maximum value of the process value

FIC_ServMedium

The process tag has the following different configuration when compared to the "Temperature-Flow-Cascade" technical function.

Table 3-24

Module	Connection	Value	Usage
C	Gain	2.769	Controller gain
C	TI	1.639	Controller lag
C	SP_InHiLim	400.0	Maximum value of the internal setpoint
PV	Scale	400.0	Maximum value of the process value
PV	PV_InUnit	1349	Unit of the process value (m^3/h)

3.7 Pressure control (Pressure)

The pressure control is realized with the "Split–Range–Pressure" technical function. The pressure calculation takes place in the simulation chart.

Design

The PID controller senses the vessel pressure from the simulation chart and increases the pressure with nitrogen or decreases it (ventilation) depending on the defined value. The following table provides you with an overview of the elements.

Table 3-25

Name	Technical function / process tag type	Description
PIC_Pressure	"Split–Range–Pressure"	Controller for the split-range control with one controller output and two actuators
YC_Nitrogen	"Split–Range–Pressure"	Control valve for the nitrogen supply
YC_Exhaust	"Split–Range–Pressure"	Control valve for ventilation

Since the focus of the application is not the pressure control and no effects are simulated from a fill level change or leakage, the simulation and the configuration remain unchanged.

Note The Feature-Bit 25 is activated in the "V" block of the CFC "YC_Nitrogen" and "YC_Exhaust".

3.8 Mixing (Agitation)

Design

The mixer stirs the educts in the reactor. This is turned on or off by the plant operator or via a step sequencer. If a fill level comes below 30% of the reactor, the interlocking of the mixer is activated. The following table provides you with an overview of the elements.

Table 3-26

Name	Technical function / process tag type	Description
NS_StirringMotor	"MOT_1sp_1fb_1cm__Std"	Stirring motor

NS_StirringMotor

Mixer control is done in the CFC "NS_StirringMotor", based on the "MOT_1sp_1fb_1cm__Std" process tag type. This process tag type is used for motors that have a constant rpm and forms part of the master data library. The "OperatingRange" "Limit" block has been additionally added in page 2 of chart partition "A" for interlocking when the fill level is falling short.

The following table shows the configuration of the instance from "MOT_1sp_1fb_1cm__Std".

Table 3-27

Module	Connection	Value	Usage
OperatingRange	OutHiLim	30	Limiting value that indicates if the fill level has been exceeded
OperatingRange	OutHiAct		Interconnection for the interlocking (Intlock.In01)

3.9 Concentration and melt flow index (product)

The multivariable control regulates the concentrations of hydrogen, comonomer and monomer (reaction conditions) as well as the melt flow index (MFI) as a measure of product quality. To this end, the controller defines its manipulated variables as external setpoint values for the downstream controls of the comonomer flow, hydrogen flow, catalyst flow, and reactor temperature.

The density calculated in the process simulation is additionally displayed in a separate measuring point.

The product quality is not directly measurable in a polymerization reactor, but is determined by laboratory samples. Therefore, a soft sensor calculates the two most important parameters of the product quality: the melt flow index and the density of the polymer. This soft sensor is based on a physical model. Since the sensor has to be developed for a specific application, it is not part of this sample solution.

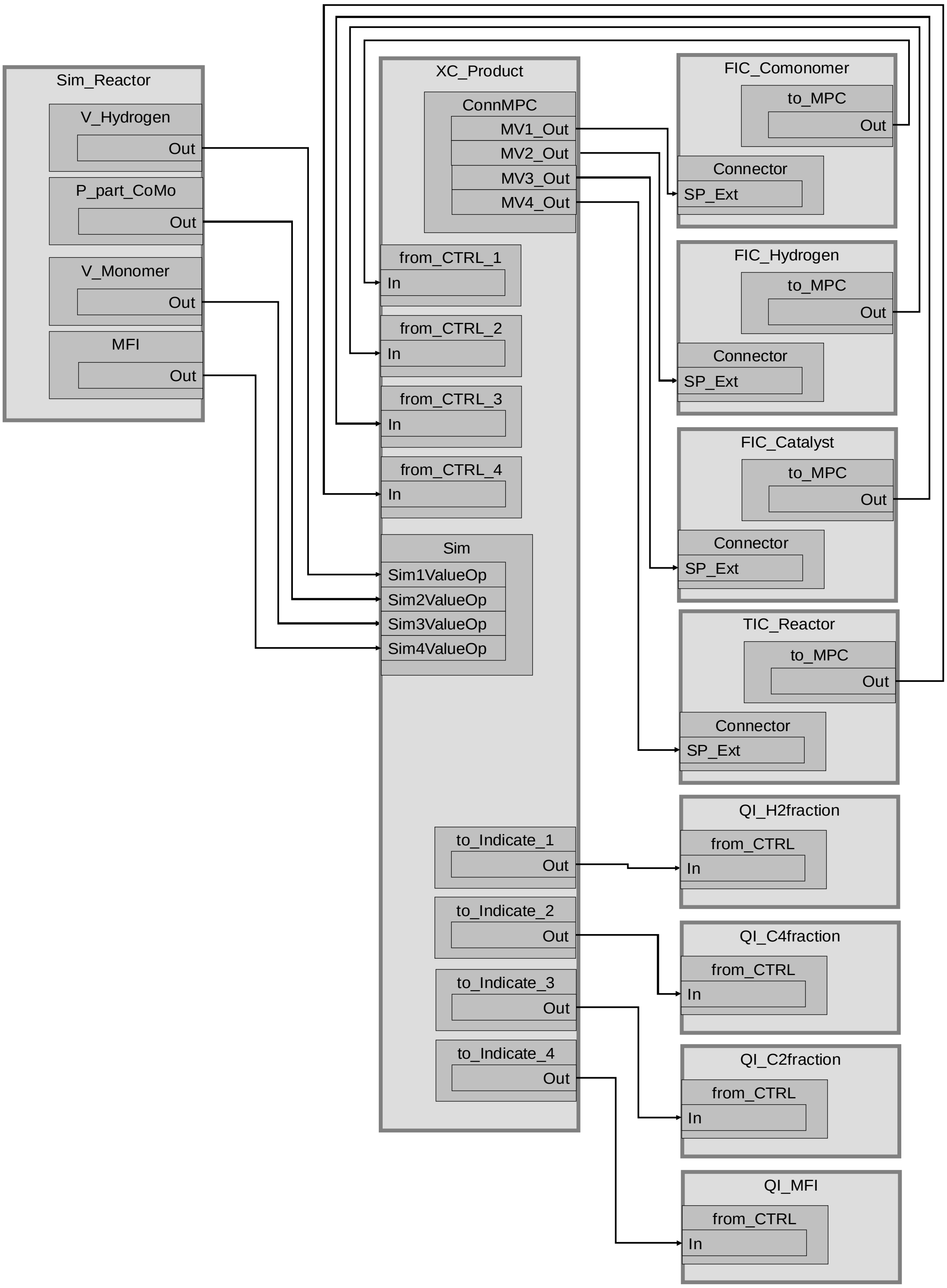
The following table provides you with an overview of the elements

Table 3-28

Name	Process tag type	Description
XC_Product	"CTRL_MPC"	Multivariable controller as a master controller
QI_MFI	"AMON_Connect"	Measuring point for displaying the melt flow index
QI_H2fraction	"AMON_Connect"	Measuring point for displaying the H2 concentration
QI_C4fraction	"AMON_Connect"	Measuring point for displaying the C4 concentration
QI_C2fraction	"AMON_Connect"	Measuring point for displaying the C2 concentration
QI_Density	"AMON__Std"	Measuring point for displaying the polymer density

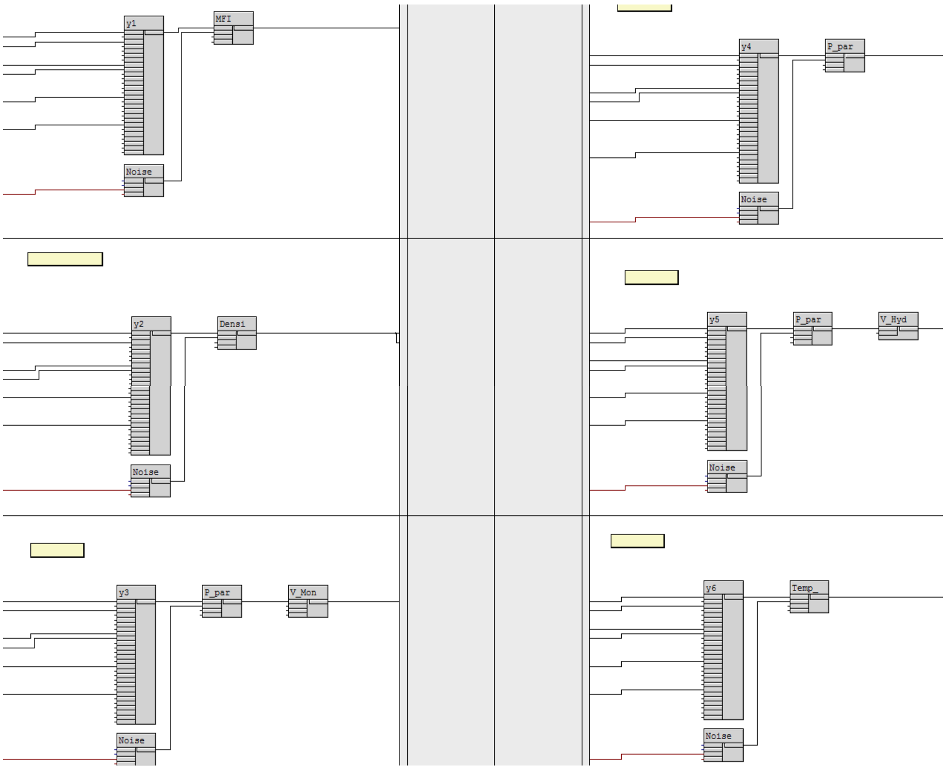
In the following figure the structure with the cross-chart interconnection is depicted in simplified form.

Figure 3–10



Simulation

Figure 3–11



In the "Sim_Reactor" simulation chart, a process variable is calculated in each sheet. Operating points, delays and interactions are defined for each process variable. The dynamic model describes deviations from the operating points for each process variable.

For a description of the simulation, please refer to Chapter "Process simulation (Simulation)".

Parameter assignment

XC_Polymer

For controlling with the multivariable controller measurement point "XC_Polymer", the following variables are used and interconnected.

CVs (Controlled Variables):

- H2fraction
- C4fraction
- C2fraction
- MFI

MVs (Manipulated Variables, setpoint values for subordinate slave controllers):

- Flow volume of comonomer educt
- Flow volume of hydrogen educt
- Flow volume of catalyst
- Temperature inside the reactor

The process tag contains communications modules for connecting slave controllers and for displaying control variables, and is an instance from the process tag type "CTRL_MPC".

Note The process tag type "CTRL_MPC" is designed for three measured and controlled variables. Four measured and controlled variables are needed at the reactor, which is why the blocks "MV4_TrkOn", "from_CTRL_4", "to_Indicate_4", "PV4", "Sqrt4" were additionally designed.

Table 3-29

Module	Connection	Value	Usage
MPC	MV1Man	138.0	Manipulated variable in setup mode
MPC	MV2Man	21.6	Manipulated variable in setup mode
MPC	MV3Man	30.6	Manipulated variable in setup mode
MPC	MV4Man	85.5	Manipulated variable in setup mode
MPC	MV1HiLim		Switched and interconnected visibly with (from_CTRL_1.ReStru1)
MPC	MV1LoLim		Switched and interconnected visibly with (from_CTRL_1.ReStru2)
MPC	DB_No	18	DB number with controller data
MPC	Restart	1	Restart and import of the data from the DB
MPC	CV4_Unit	g / 10min	The user-specific unit has been entered in the line "CV4_Unit" and column "Unit" of the object properties of the MPC
SP10ptHiLim	In2	0.5	SP1 upper limit for MPC optimization
SP10ptLoLim	In2	-0.5	SP1 lower limit for MPC optimization
SP20ptHiLim	In2	0.1	SP2 upper limit for MPC optimization
SP30ptLoLim	In2	-0.1	SP2 lower limit for MPC optimization
SP30ptHiLim	In2	1.0	SP3 upper limit for MPC optimization
SP30ptLoLim	In2	-1.0	SP3 lower limit for MPC optimization
SP40ptHiLim	In2	0.1	SP4 upper limit for MPC optimization
SP40ptLoLim	In2	-0.1	SP4 lower limit for MPC optimization
ConnMPC	MV1Out		Manipulated variable for the comonomer flow (Feed\\FIC_Comonomer\Connector.SP_Ext)
ConnMPC	MV2Out		Manipulated variable for the hydrogen flow (Feed\\FIC_Hydrogen\Connector.SP_Ext)
ConnMPC	MV3Out		Manipulated variable for the catalyst flow (Feed\\FIC_Catalyst\Connector.SP_Ext)
ConnMPC	MV4Out		Manipulated variable for the product temperature (AirSupply\\FIC_HotAir\Connector.SP_Ext)
from_CTRL_1	In		Interconnection of the comonomer measuring point (Feed\\FIC_Comonomer\to_MPC.Out)
from_CTRL_2	In		Interconnection of the hydrogen measuring point (Feed\\FIC_Hydrogen\to_MPC.Out)
from_CTRL_3	In		Interconnection of the catalyst measuring point (Feed\\FIC_Catalyst\to_MPC.Out)

Module	Connection	Value	Usage
from_CTRL_4	In		Interconnection of the product temperature measuring point (Cooling\\TIC_Polymer\to_MPC.Out)
to_Indicate_1	Out		Interconnection for the H2 fraction display (Product\\QI_H2fraction\from_CTRL.In)
to_Indicate_2	Out		Interconnection for the C4 fraction display (Product\\QI_C4fraction\from_CTRL.In)
to_Indicate_3	Out		Interconnection for the C2 fraction display (Product\\QI_C2fraction\from_CTRL.In)
to_Indicate_4	Out		Interconnection for the flow index display (Product\\QI_MFI\from_CTRL.In)
Sim	Sim1ActOp.Value	1	Activation of the simulation
Sim	Sim1ValueOp		Interconnection for the simulated product temperature (Process\Simulation\Sim_Reactor\V_Hydrogen.Out)
Sim	Sim2ActOp.Value	1	Activation of the simulation
Sim	Sim2ValueOp		Interconnection for the simulated product moisture content (Process\Simulation\Sim_Reactor\P_part_CoMo.Out)
Sim	Sim3ActOp.Value	1	Activation of the simulation
Sim	Sim3ValueOp		Interconnection for the simulated product moisture content (Process\Simulation\Sim_Reactor\V_Monomer.Out)
Sim	Sim4ActOp.Value	1	Activation of the simulation
Sim	Sim4ValueOp		Interconnection for the simulated product moisture content (Process\Simulation\Sim_Reactor\MFI.Out)
PV1	Scale	50.0	Maximum value of the process value
PV1	PV_InUnit	1562	Process value unit (%vol)
PV2	Scale	4.0	Maximum value of the process value
PV2	PV_InUnit	1562	Process value unit (%vol)
PV3	PV_InUnit	1562	Process value unit (%vol)
PV4	Scale	2.5	Maximum value of the process value
PV4	PV_InUnit	0	Process value unit

Note If a setpoint range (control range of a slave controller) is less than 0 or greater than 100, the corresponding speed range at the MPC input parameters "MVxHiLim" and "MVxLoLim" needs to be adjusted or additionally connected to the communication block "from_CTRL_x" and the parameters of the upper speed range "ReStru1" and lower speed range "ReStru2".

Note Commissioning of the multivariable controller was carried out based on the "fluidized bed dryer" application description of a model predictive controller, with working point optimization. You will find the example under the Entry ID: 61926069. Before optimizing the controller, it is important to carry out an excitation for each manipulated variable (MPC in "Manual" operating mode) and to wait until the excitation completes for all process data.

QI_H2fraction

The display measuring point is used for the display and monitoring of the hydrogen (H2) concentration for the multivariable control measuring point. The operator can set alarm and warning limit values.

The following table shows the configuration of the instance from "AMON_Connect".

Table 3-30

Module	Connection	Value	Usage
from_CTRL	In		Interconnection to the controlled variable of the multivariable controller (XC_Polymer\to_Indicate_1.Out)

QI_C4fraction

The display measuring point is used for the display and monitoring of the comonomer (C4) concentration of the multivariable control measuring point. The operator can set alarm and warning limit values.

The following table shows the configuration of the instance from "AMON_Connect".

Table 3-31

Module	Connection	Value	Usage
from_CTRL	In		Interconnection to the control variable of the multivariable controller (XC_Product\to_Indicate_2.Out)

QI_C2fraction

The display measuring point is used for the display and monitoring of the monomer (C2) concentration of the multivariable control measuring point. The operator can set alarm and warning limit values.

The following table shows the configuration of the instance from "AMON_Connect".

Table 3-32

Module	Connection	Value	Usage
from_CTRL	In		Interconnection to the controlled variable of the multivariable controller (XC_Product\to_Indicate_3.Out)

QI_MFI

The display measuring point is used for the display and monitoring of the melt flow index (MFI) of the multivariable control measuring point. The operator can set alarm and warning limit values.

The following table shows the configuration of the instance from "AMON_Connect".

Table 3-33

Module	Connection	Value	Usage
from_CTRL	In		Interconnection to the controlled variable of the multivariable controller (XC_Product\to_Indicate_4.Out)
I	PV_Unit	g / 10min	The user-specific unit has been entered in the line "PV_Unit" and column "Unit" of the object properties

QI_Density

The display measuring point is used to display and monitor the polymer density. The density is calculated in the process simulation and only connected for display purposes. The operator can set alarm and warning limit values.

The following table shows the configuration of the instance from "AMON__Std".

Table 3-34

Module	Connection	Value	Usage
Sim	Sim1ActOp	1	Activate the simulation values
Sim	Sim1ValueOp		Interconnection for the simulated process value (Process\Simulation\\Sim_Reactor\Density.Out)
PV	Scale	1000.0	Maximum value of the process value
PV	PV_InUnit	1097	Unit of the process value (kg/m^3)

3.10 Process simulation (Simulation)

The CFC chart "Sim_Reactor" contains all of those parts of the simulation model that not only describe an individual system section but also have an overarching nature. The role of process simulation is to understand the functioning of the polymerization reactor, particularly in relation to the control functions of the multivariable controller or to be able to demonstrate it. It does not claim to replicate exactly the real physical behavior of a particular reactor.

A matrix with linear, dynamic transfer functions is used as a model for process simulation. The process model is a 6x4 multi-variable system, whereby the influence of each input variable on every output variable is simulated by a separate partial transfer function. The model describes the temporal behavior of process deviations from the working point. The process simulation runs in time lapse, i.e. 100 times faster than real-time.

Note The CFC chart "Presettings" allows you to set the time lapse as well as reset the delays and activate or deactivate the process noise.

Furthermore, the operating points lag times and downtimes can be parameterized for each process variable. The partial transfer functions are realized with different dynamic models (PT_1, PT_2 or PT_3 behavior). Each partial transfer function receives the respective differential value from the predefined working point and the current value of the input variables and outputs them correspondent to its transfer functions at the output point. At the end, for each process output variable yi the associated working point is added.

Note All PT_n transfer functions are structured as 'chart in chart' according to the same principle, whereby only the required functional parts are activated. A transfer function contains three sequentially switched delay elements and a booster element. Furthermore, noise can be added to the output signal

In the following figure, the process model is depicted with the corresponding names.

Figure 3–12: Partial transfer functions of the process model

input variables

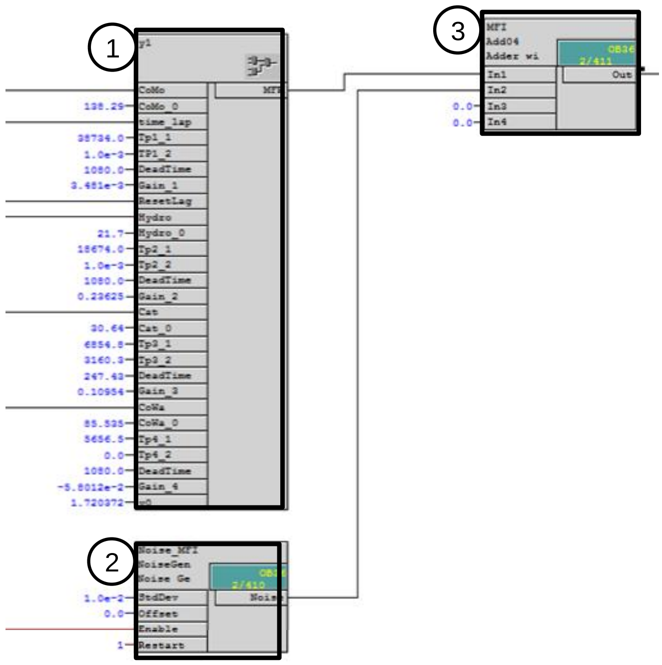
output variables	Feed Comonomer	Feed Hydrogen	Feed Catalyst	Feed ServMedium
MFI	y1u1	y1u2	y1u3	y1u4
Density	y2u1	y2u2	y2u3	y2u4
V_Monomer	y3u1	y3u2	y3u3	y3u4
P_part_CoMo	y4u1	y4u2	y4u3	y4u4
V_Hydrogen	y5u1	y5u2	y5u3	y5u4
Temp_Polymer	y6u1	y6u2	y6u3	y6u4

The process variables "MFI" (melt flow index), "V_Monomer" (concentration of the monomer), "P_part_CoMo" (concentration of the comonomer) and "V_Hydrogen" (concentration of hydrogen) are required for multivariable control. The process variable "Temp_Polymer" is used to control the polymer temperature in the reactor, and "Density" to show the polymer density.

Note The numbering of the process variables does not match the numbering of the controlled variables of the MPC, but corresponds to the arrangement in the CFC chart.

The following figure shows the simulation block (chart-in-chart) of Sheet 1 for the calculation of the MFI (melt flow index). Different process values are calculated in the same way with different parameters in each sheet.

Figure 3-13



1. **Calculation of the MFI**
   The MFI is calculated in this block. The associated operating point as well as the delays (TPx_x), the dead time (DeadTime) and the gain (gain_x) are all specified under each connected parameter. In the block, the deviations on the operating point are calculated, added together and sent to the output in individual transfer functions for each interconnected manipulated variable (comonomer, hydrogen, catalyst and cooling water to the heat exchanger).
2. **Process noise**
   In this block, an artificial error is created in the form of a fluctuation in the block. This error, as well as all other errors of the process simulation, is activated centrally in the CFC "Presettings".
3. **Output value**
   In this block, the process value, if enabled, is given with accumulated process noise.

3.11 Sequencers

At the start of production, the plant is run dry, the reactor is purged with nitrogen and then taken into production operation whereby the individual plant components approach their operating points.

Note The composition and viscosity of the product produced at the beginning of the startup process does not meet the specified criteria, so that after a few minutes the desired or pre-selected product quality is delivered.

Sequencers support the plant operator during start-up and shut-down of a plant or during errors.

During start-up the process is placed in the defined operating point. The controllers are optimized for the specific operating point and are switched to automatic mode when reaching the operating point. This example takes the control of multivariable controllers after approaching the specified product quality (concentration, and melt flow index).

Different behavior and modes of operation can be realized in SFC. In the sample project the SFC "StartReactor" is configured for automatic start-up without user interaction. After start-up, the controller is transferred to the user in automatic mode, allowing him to determine, for instance, the individual setpoint values.

The following sequencers are components of the SFC and are described below:

- PREPARING
- STARTUP
- RUNNING

The SFC are designed for the simulation and can only be understood as a reference points for real plants, i.e. if necessary, they have to be modified for use in real systems.

Note To determine the setpoint value and operating mode selection, the necessary parameterization is used, incl. the schematic representations from the function manual "SIMATIC Process Control System PCS 7 Advanced Process Library (V8.0 SP1)". In the function manual under the Entry ID: 68154793 you can find information on operating modes and setpoint value selection, as well as more detailed information on all parameters of the APL blocks.

PREPARING

When starting the polymerization reactor, the sequencer (sequence) "PREPARING" is performed at the beginning, which runs the unit in a non-production operation. For this, all inflows are stopped, the reactor is emptied and flushed with nitrogen.

The operational modes of all controllers except the pressure and level control switch to automatic and are updated to the manipulated variable "0".

The pressure control and level control receive external setpoint values.

STARTUP

The sequencer "STARTUP" follows the sequencer "PREPARING". During the starting phase, the unit from the plant standstill (no production) is prepared for operation in its normal state. To accomplish this, all controllers receive external setpoint values and the tracking is stopped.

The following steps are performed in the sequencer:

1. Temperature control of the jacket temperature at 20°C
2. Reactor fill level (setpoint value) of 60%
3. Setting the MPC setpoint values (concentrations and melt flow index) and manipulated variables for the tracking.
4. Setpoint value specification for all inflows and product temperature. All MPC slave controllers receive internal setpoint values, while the remaining controllers receive external setpoint values. The diluent pump is additionally activated.
5. The remaining pumps and the mixer are activated after reaching a fill level of 30%. The vessel also receives a setpoint value specification for the vessel pressure.
6. After reaching the specified process variables (concentrations and melt flow index), the MPC goes into automatic mode and all slave controllers use the external setpoint value (manipulated variable of the MPC) for control.

Note The MPC is taken in automatic mode, as long as the subordinate controllers still run with an internal setpoint value. As a result, all MPC outputs are tracked to the correct values from the sequence control circuits. The subordinate controllers are then switched to external setpoint values and the MPC switches smoothly channel-by-channel from tracking into automatic mode.

RUNNING

In the sequencer "RUNNING", operator input is enabled for all controllers and aggregates. To this end, the following parameters are changed:

- for PID controllers: "ModLiOp" = 0 and "SP_LiOp" = 0
- for MPC controllers: "ModLiOp" = 0
- for aggregates (pumps und mixers): "ModLiOp" = 0

Upon successful execution of the sequencer, the operator can define new setpoint values for the controller.

Note The setpoint values of the slave controller from the motor staging cannot be changed due to the pre-defined program logic. At the ratio blocks, you can individually customize the inflows and therefore the setpoint values of the slave controller of the ratio control.

3.12 Process parameters (KPI)

The CFC chart "KPI" comprises key performance indicators that inform the operator about the process performance. The following key performance indicators are calculated and shown in the visualization:

1. Sheet dwell time (ResidenceTime): The dwell time is calculated from the quotient of the reaction volume and exiting volume flow. During this process, the reaction volume is calculated from the normalized fill level. The outflowing volume flow $\dot{V}_{Product,out}$ corresponds to the product outflow of the fill level control loop.

$$\tau = \frac{l \times V}{100\% \times V_{Product,out}}$$

2. Space-time-yield sheet (SpaceTimeYield): The space-time-yield describes the ratio between the incoming mass flows of educts $\dot{m}_{E,in}$ and the total volume of the reactor V_R . Since the inflows are partially present as mass flows and partially as volume flows in the simulation, the following relationship results for this application.

$$RZA = \frac{\dot{m}_{E,in}}{V_{\mathrm{R}}}$$

$$\dot{m}_{E,in} = \dot{m}_{Comonomer,in} + \dot{m}_{Monomer,in} + \dot{m}_{Catalyst,in} + \rho_{Hydrogen} \times \dot{V}_{Hydrogen,in}$$

3. Catalyst productivity sheet (CatProductivity): The catalyst productivity KA is derived from the ratio between the outflowing mass flow of the product $\dot{m}_{Product,out}$ and the inflowing mass flow of the catalyst $\dot{m}_{Catalyst,in}$.
   The density of the product is thereby calculated by the simulation model:
   $\rho_{Product} = y_2$ (See also Process simulation (Simulation)).

$$KA = \frac{\dot{m}_{Product,out}}{\dot{m}_{Catalyst,in}} = \frac{\rho_{Product} \cdot \dot{V}_{Product,out}}{\dot{m}_{Catalyst,in}}$$

Note The value for the catalyst productivity is coupled to the product discharge and changes according to the controller output of the discharge valve. Due to the predefined control gain factor, changes to the manipulated variables produce major value fluctuations. In practice, it is not the short-term fluctuations, but rather the long-term changes of the temporal mean value of the catalyst productivity that are preferred.

3.13 Task-related overview images with APG

With PCS 7 Advanced Process Graphics, process pictures are displayed more clearly, reduced to the essential and are intuitive to use. The focus lies in the consideration of the relevant process variables within the working ranges.

3.13.1 Integration of APG

The integration of APG is configured in two phases:

1. Insertion and configuration of APG blocks in the measuring points (AS)
2. Placement and interconnection of APG objects (OS)

Note You can find basic information about APG, for extension of an existing PCS 7 project with APG and for configuration purposes in the application description "Integration of Advanced Process Graphics in SIMATIC PCS 7" under the Entry ID: 89332241.

3.13.2 APG measuring points (AS)

Two different range representations (ViewMode) are set in the project. The bar graphs in the Level 2 process picture show the process value in the differential representation, while in the Level 1 process picture, the bar graphs show the value in the absolute representation.

Controller measuring points

All controller measuring points of the polymerization reactor contain an instance of the APG connector block in "Sheet 1" of the chart partition "A" and are all interconnected and parameterized as follows:

Table 3-35

Connection	Value	Usage
BockType	2	Representation suitable for the "PIDConL" block
ViewMode	1	Absolute representation (value range)
ViewRange	4	Display of the working range
ReadPointer		Connected with "C.Status2"

The following values are configured for the boundaries of the HMI instances:

Table 3-36

Measuring point	Connection	Value	Usage
FIC_Catalyst	PV_OH_Li	40.0	Upper limit of the working range
FIC_Catalyst	PV_OL_Li	15.0	Lower limit of the working range
FIC_Cocatalyst	PV_OH_Li	2.5	Upper limit of the working range
FIC_Cocatalyst	PV_OL_Li	0.0	Lower limit of the working range
FIC_Hydrogen	PV_OH_Li	35.0	Upper limit of the working range
FIC_Hydrogen	PV_OL_Li	15.0	Lower limit of the working range
FIC_Comonomer	PV_OH_Li	200.0	Upper limit of the working range

Measuring point	Connection	Value	Usage
FIC_Comonomer	PV_OL_Li	100.0	Lower limit of the working range
FIC_Monomer	PV_OH_Li	6300.0	Upper limit of the working range
FIC_Monomer	PV_OL_Li	5700.0	Lower limit of the working range
FFIC_Diluent	PV_OH_Li	48.0	Upper limit of the working range
FFIC_Diluent	PV_OL_Li	15.0	Lower limit of the working range
LIC_Reactor	PV_OH_Li	80.0	Upper limit of the working range
LIC_Reactor	PV_OL_Li	45.0	Lower limit of the working range
PIC_Reactor	PV_OH_Li	9.0	Upper limit of the working range
PIC_Reactor	PV_OL_Li	6.0	Lower limit of the working range
TIC_Polymer	PV_OH_Li	90.0	Upper limit of the working range
TIC_Polymer	PV_OL_Li	80.0	Lower limit of the working range
FIC_ServMedium	PV_OH_Li	110.0	Upper limit of the working range
FIC_ServMedium	PV_OL_Li	70.0	Lower limit of the working range
TIC_Jacket	PV_OH_Li	22.0	Upper limit of the working range
TIC_Jacket	PV_OL_Li	18.0	Lower limit of the working range

Display measuring point

All display measuring points "QI_xxxxxx" contain two instances of the APG connector block in "Sheet 1" of chart partition "A", the instance "HMI" for the absolute representation of the process value and the instance "HMI_2" for the differential representation. The measuring points are interconnected and parametrized as follows:

Table 3-37

Module	Connection	Value	Usage
HMI HMI_2	BockType	1	Representation suitable for the "PIDConL" block
HMI	ViewMode	1	Absolute representation (value range)
HMI_2	ViewMode	2	Differential representation (value range)
HMI HMI_2	ViewRange	4	Display of the working range
HMI HMI_2	ReadPointer		Connected with "C.Status2"

The following values are configured in the same way for each measuring point of the boundaries of the "HMI" and "HMI_2" instances:

Table 3-38

Measuring point	Connection	Value	Usage
QI_MFI	PV_OH_Li	2.5	Upper limit of the working range
QI_MFI	PV_OL_Li	1.0	Lower limit of the working range
QI_C2fraction	PV_OH_Li	68.5	Upper limit of the working range
QI_C2fraction	PV_OL_Li	60.0	Lower limit of the working range
QI_C4fraction	PV_OH_Li	1.8	Upper limit of the working range

Measuring point	Connection	Value	Usage
QI_C4fraction	PV_OL_Li	1.0	Lower limit of the working range
QI_H2fraction	PV_OH_Li	29.0	Upper limit of the working range
QI_H2fraction	PV_OL_Li	24.0	Lower limit of the working range
QI_Density	PV_OH_Li	950.0	Upper limit of the working range
QI_Density	PV_OL_Li	940.0	Lower limit of the working range

KPI measuring point

The measuring point "KPI" contains three instances of the APG connector block to display the process parameters. The measuring point is interconnected and parametrized as follows:

Table 3-39

Module	Connection	Value	Usage
HMI_1	BockType	1	Representation suitable for the "MonAnL" block
HMI_1	ViewMode	1	Absolute representation (value range)
HMI_1	ViewRange	4	Display of the working range
HMI_1	ReadPointer		Connected with "ResidenceTime.Status2"
HMI_1	DispRatio	0.6	Ratio of display to ViewRange
HMI_1	PV_OH_Li	0.6	Upper limit of the working range
HMI_1	PV_OL_Li	0.01	Lower limit of the working range
HMI_2	BockType	1	Representation suitable for the "MonAnL" block
HMI_2	ViewMode	1	Absolute representation (value range)
HMI_2	ViewRange	4	Display of the working range
HMI_2	ReadPointer		Connected with "SpaceTimeYield.Status2"
HMI_2	DispRatio	0.6	Ratio of display to ViewRange
HMI_2	PV_OH_Li	180.0	Upper limit of the working range
HMI_2	PV_OL_Li	100.0	Lower limit of the working range
HMI_3	BockType	1	Representation suitable for the "MonAnL" block
HMI_3	ViewMode	1	Absolute representation (value range)
HMI_3	ViewRange	4	Display of the working range
HMI_3	ReadPointer		Connected with "CatProductivity.Status2"
HMI_3	DispRatio	0.6	Ratio of display to ViewRange
HMI_3	PV_OH_Li	400.0	Upper limit of the working range
HMI_3	PV_OL_Li	300.0	Lower limit of the working range

3.13.3 APG objects (OS)

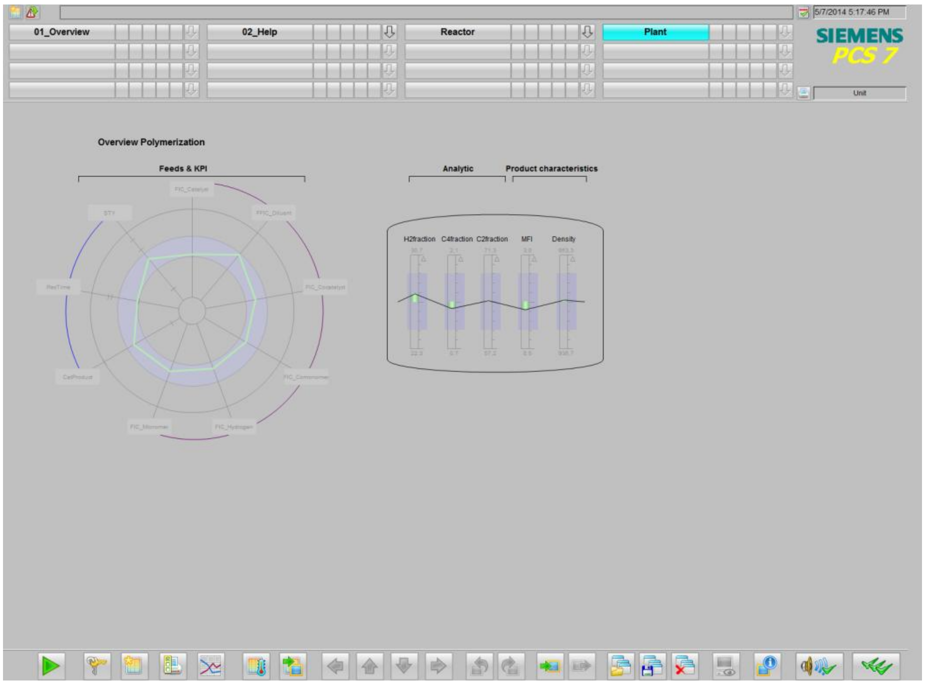
In order to provide the operator with an optimum working environment, the following two process pictures were created:

- Level 1 process picture for orientation and navigation (system overview)
- Level 2 process picture for operator control and monitoring of a device, in this case, the polymerization reactor

Note You can find detailed information and the procedure for configuring APG in the Siemens Industry Online Support in the article "Integration of Advanced Process Graphics in SIMATIC PCS 7" under the entry ID 89332241.

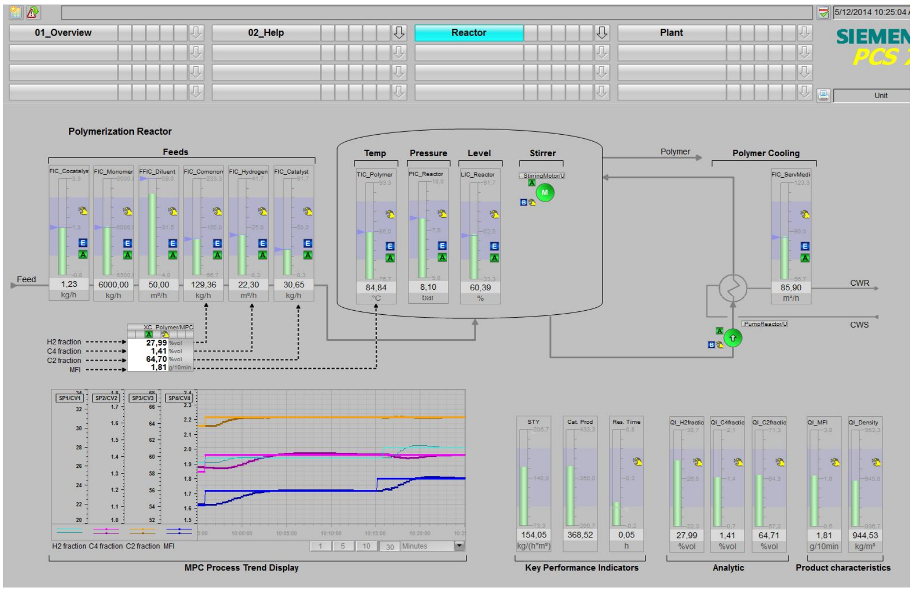
Level 1 process picture (orientation and navigation)

A process picture with a compressed representation of the main driving parameters is available for the monitoring of the process-related parameters of the overall system. This allows the overall context to be quickly detected and impressed as a pattern.



Level 2 process picture (operator control and monitoring)

Another process picture is available for the monitoring of the process-related parameters of the reactor and also for operator control, which schematically represents the most important process values and control of the reactor. This representation has the advantage that large volumes of data can be combined to form a compressed and clear display of information.

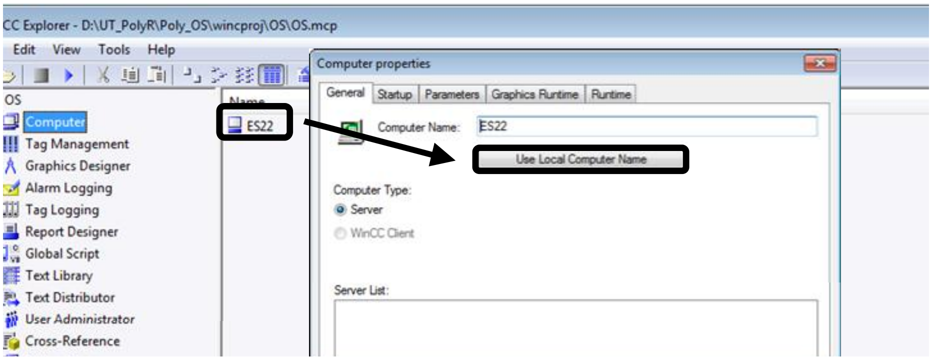


4 Starting of the Unit template

4.1 Preparations

The following instructions describe putting the Unit template into service by simulating the controller with the "S7-PLCSIM" program. If there is a real controller, you must configure existing hardware components in the HW Config.

Table 4-1

No.	Action
1.	Copy the file "84061788_PolyReactor_PCS7V801.zip" into any folder on the configuration PC and then open the SIMATIC Manager.
2.	In the menu bar, click on "File > Retrieve" and select the file "84061788_PolyReactor_PCS7V801.zip". Then confirm with "Open".
3.	Select the folder in which the project should be saved and confirm by pressing "OK". The project will be retrieved.
4.	Confirm the "Retrieve" dialog with the "OK" button and then click on "Yes" in the dialog to open the project.
5.	Right-click on "UT_PolyReactor_OS > SVES4ALL02 > WinCC Appl. > OS" and click on the menu command " open object".
6.	Confirm the "Configured server not available" dialog with "OK".
7.	In the WinCC Explorer, open the characteristics of your computer and, in the opened Characteristics dialog, click on the "Adopt local computer name" button. Click the "OK" button to confirm the message "Change PC name". 
8.	In the WinCC Explorer, click on "File > End" and, in the subsequent dialog, select "Terminate WinCC Explorer and close project". Then confirm with OK.
9.	Reopen the WinCC Explorer as described in step 5.
10.	Open by double-clicking on "Variables library". In the "WinCC Configuration Studio", right-click on "Variables library > SIMATIC S7 Protocol Suite > Industrial Ethernet" and select the menu command "System parameters".
11.	In the "Unit" register, check the "Logical device names" setting. If the "S7-PLCSIM" is used, the device name PLCSIM(ISO) is selected. If the device name is changed, the program must be restarted. Reopen the WinCC Explorer as described in step 5. **Note** If the OS cannot establish a connection with the AS (grayed out image modules), select the logical device name "CP_H1_1:" and restart the OS.

4.2 Commissioning

The following instructions describe how the Unit template is initialized.

To put into service, it is required that SIMATIC Manager is already open and that the project has been selected in the component view.

Starting the simulation (S7-PLCSIM)

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

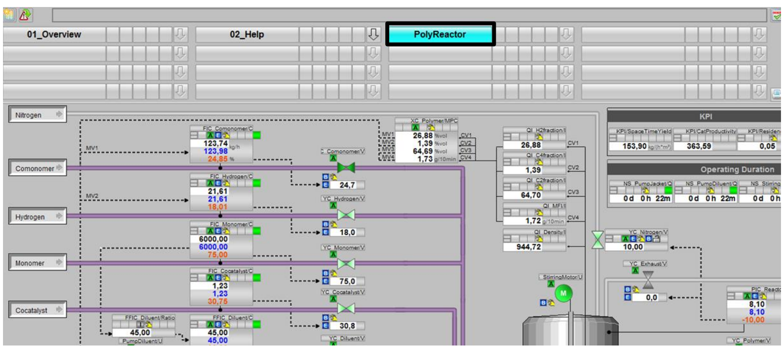
Table 4-2

No.	Action
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 the file "PolyReactor.plc" from the path <Project path>\UT_PolyR\PolyReactor\PolyReactor.plc>.
4.	In the menu, select "Execute > Key-switch position > RUN-P".
5.	Switch to the component view of the SIMATIC Manager and mark "UT_PolyRactor_AS > AS01".
6.	In the menu bar, click on "Target system > Load" and confirm the "Load" dialog with "Yes". Confirm the "Stop target group" dialog with "OK" and the subsequent "Load" dialog with "Yes".

Activate OS (WinCC Runtime)

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

Table 4-3

No.	Action
1.	Right-click on "UT_PolyReactor_OS > SVES4ALL02 > WinCC Appl. > OS" and click on the menu command " open object".
2.	To activate the OS (WinCC Runtime), select "File > Activate" in the WinCC Explorer menu.
3.	In the "System Login" dialog, enter as "Login" the user "Unit" and "Template" as the password; confirm with "OK".
4.	Select the Unit template "PolyReactor" in the image area.  **Note** The polymerization reactor is already located in the production process because the AS program execution (PLCSIM) has been started.

5 Operation of the application

5.1 Overview

Some of the polymerization reactor's components can be operated and monitored by means of the process picture. In addition, the plant operator receives information (KPI's) for the current process.

Note Please note that after CPU start it takes about 15 minutes until the plant goes in production operation, which meets the specified quality requirements. During the running production operation, all controllers are enabled. You can identify this state in the SFC when it has successfully processed all sequences, among others.

The following scenarios relate to the handling of the "Polymerization Reactor" unit template:

- Procedure for controller optimization
- MPC working point optimization
- Monitoring the progress of the process with APG

5.2 Scenario A –Procedure for controller optimization

Thanks to its wide range of control loops, this application offers a great way to perform optimizations for individual control loops, starting with simpler controls, such as fill level control, to complex multivariable controls for polymerization. The basic procedure for controller optimization is described in the following.

After a successful startup of the plant, all controllers are enabled, so that separate setpoint values can be specified after switching to the internal setpoint value.

Standard PID controller

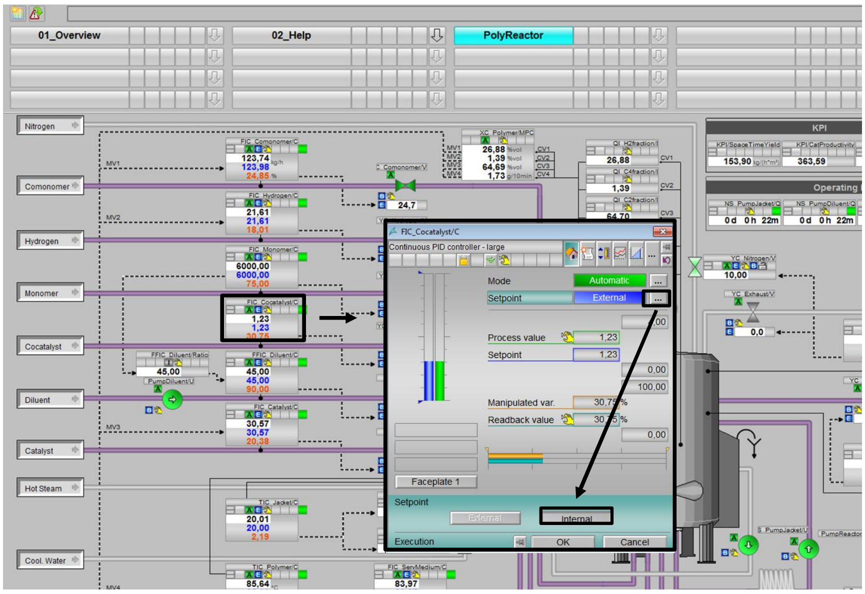
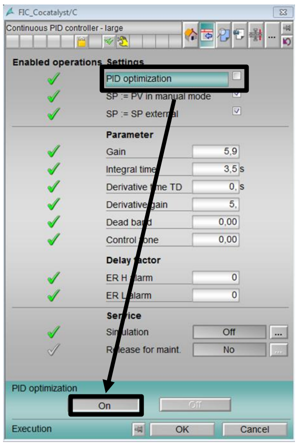
The PID controls, with the exception of the slave controller of the MPC and the motor staging, operate independent from the process simulation of the MPC.

The Following optimization is explained using the example of the flow "FIC_Cocatalyst" and described only until the optimization dialog. A detailed description for the controller optimization can be found in the application notes:

- "Equipment Modules for PCS 7 using the example of the Chemical Industry" under the entry ID: 53843373, in chapter "Configuration of the PID controller"
- "PID Control with Gain Scheduling and PID Tuning" under the entry ID: 38755162

Table 5-1

No.	Action
1.	In the OS, switch to the process picture and select the block icon "FIC_Cocatalyst". This will open the corresponding faceplate.

<table>
<tr><th>No.</th><th>Action</th></tr>
<tr><td>2.</td><td>Change the setpoint value specification to the internal setpoint value.

Note
The setpoint value is tracked so that the switchover does not bring about any changes.</td></tr>
<tr><td>3.</td><td>Change the faceplate in the "Parameters" range and activate the setting "PID optimization".
</td></tr>
<tr><td>4.</td><td>Switch to the SIMATIC Manager and open the chart partition "A", sheet "1" of the CFC chart "FIC_Cocatalyst".</td></tr>
<tr><td>5.</td><td>Select the controller block "C" and choose the menu command "Edit> Optimize PID controller ...".</td></tr>
<tr><td>6.</td><td>Carry out the controller optimization.
Note
Please note that the flow does not consist an integral part and the excitation to the optimization does not deviate much from the operating point.</td></tr>
</table>

Note If the operating point changes, the SFC must be adapted according to the new operating point.

MPC controller

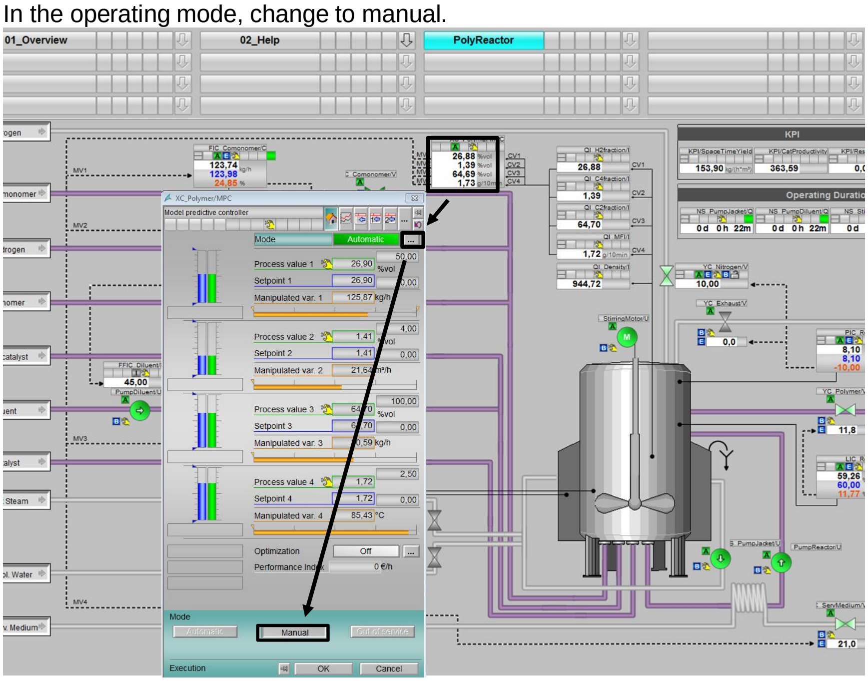
The multivariable control is applicable for slower but more sophisticated processes. Before optimizing the multivariable controller, the slave controllers must first display a stable control behavior. This relates to the example of the educt flow and the temperature control via the heat exchanger.

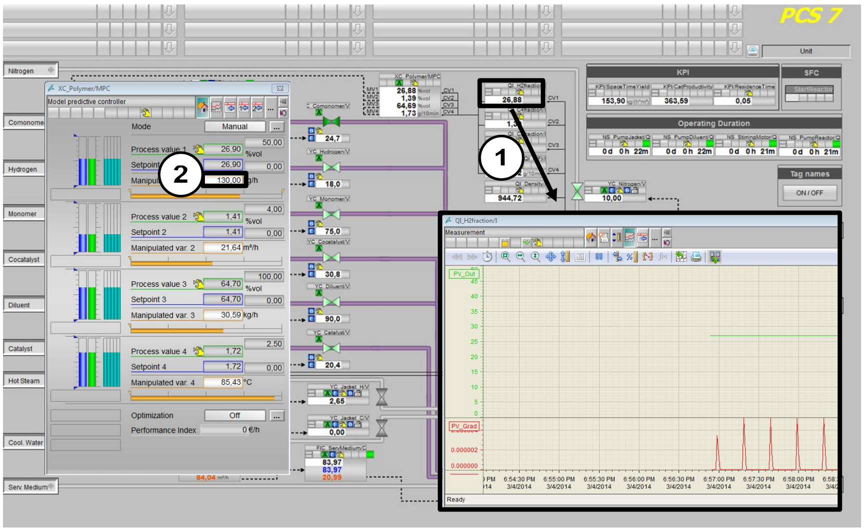
The steps are described until the optimization dialog for the following optimization. A detailed description for the MPC optimization, can be found in the application notes

- "Fluidized Bed Dryer - Design of Model Predictive Control with Economical Steady State Optimization" under the entry ID: 61926069
- "PCS 7 Unit Template "Distillation Column" using the example of the Chemical Industry" under the entry ID: 48418663, in chapter "Configuration of the MPC controller"

Note Please note that in the listed applications, MPC controls are described with different numbers of controlled variables and disturbance variables. The basic procedure for controller optimization is however identical and can also be applied to this example.

Table 5-2

No.	Action
1.	In the OS, switch to the process picture and select the block icon "XC_Polymer". This will open the corresponding faceplate.
2.	In the operating mode, change to manual.  **Note** All manipulated variables are tracked so that the switchover does not bring about any changes.

No.	Action
3.	Open in order to monitor the trend display (1) of the process variable. Perform an excitation for the first setpoint value (2) and wait until the excitation process is complete.  **Note**. Depending on the controlled variable, it can take about 15 minutes until most of the excitation process is complete. From the trend diagram, you can determine the time and the influence of the excitation. This data allows you to determine the parameters for the excitation block "AutoExcitation".
4.	After the evaluation, remove, for example, the excitation in the trend display and wait again until this excitation process is complete.
5.	Carry out steps 3 and 4 for all controlled variables.
6.	Switch to the SIMATIC Manager and open the chart partition "A", sheet "1" of the CFC chart "XC_Polymer".
7.	Open the Trend display via the menu command "View> Trend display...".
8.	Add all four process values (CVx) and manipulated variables (MVx) of the trend display and parameterize the value ranges according to the configuration at the MPC. You can alternatively use the pre-made trend indicator in the MPC block. **Note** You can take the value ranges for the process values from the channel drivers in chart partition "B" of the CFC and the slave controller of the MPC for the manipulated values. Alternatively, you can use the input parameters "SPxHiLim" and "SPxLoLim" for the process value limits, "MVxHiLim" and "MVxLoLim" for the manipulated variable limits at the MPC and switch them to visible.
9.	Parameterize the "AutoExcitation" block according to your records of the excitation process for all four manipulated variables (NumberMV = 4). **Note** Set the manipulated variables and the duration of the excitation process in a way that a change in the process value can be identified.
10.	Start the trend logging and wait 30 seconds until the first values (no skips) are recorded.
11.	Start the excitation process in the visibly switched "AutoExcitation" block and wait until all excitation processes are fully completed. **Note** The excitation can take several hours, depending on the preset time.
12.	After completing the excitation, export the trend log. **Note** In the project path "<<Projekt path>\UT_PolyR\PolyReactor" you can find the exported trend log "MPC_Record_20140227.csv" for optimization.

No.	Action
13.	Select the block "MPC" and click in the menu bar "Edit > Configure MPC".
14.	In the MPC configurator, run the control design with the exported trend log.

5.3 Scenario B – MPC working point optimization

The MPC controller allows economic optimization of the stationary operating point under consideration of setpoint tolerance limits. To this end, deviations allowed by the controller (degrees of freedom) are defined, in which the setpoint values may move. This range is also referred to as the tolerance range. When the operating point optimization is activated, the controller finds the manipulated variables within the tolerance ranges, in sense of the most advantageous performance criterion.
If there is no extra information (computation of the economic data) available for the control, the lowest tolerance values are approached.

Define the performance criterion in the parameter view. To this end, you can define specific costs for each manipulated and controlled variable of the MPC that should be minimized, or revenues which should be maximized.

The example considers the following dependencies:

- The MVs 1…3 are educt streams and cause higher costs if they rise.
- The MV 4 corresponds to the reactor temperature and reduces costs when it rises. At a higher temperature, the demand for cooling energy is reduced.
- The CVs involve no costs, however they must be kept within specified tolerance ranges to produce a salable product.
- The sale revenue depends on the product outflow. In a first approximation, the discharge is equal to the sum of the educt inflows. Since the main raw material, i.e. the monomer, is supplied at a constant rate, the product discharge may also be assumed to be approximately constant.

The objective of the optimization is therefore to achieve the required specifications with the least possible use of raw materials and cooling energy.

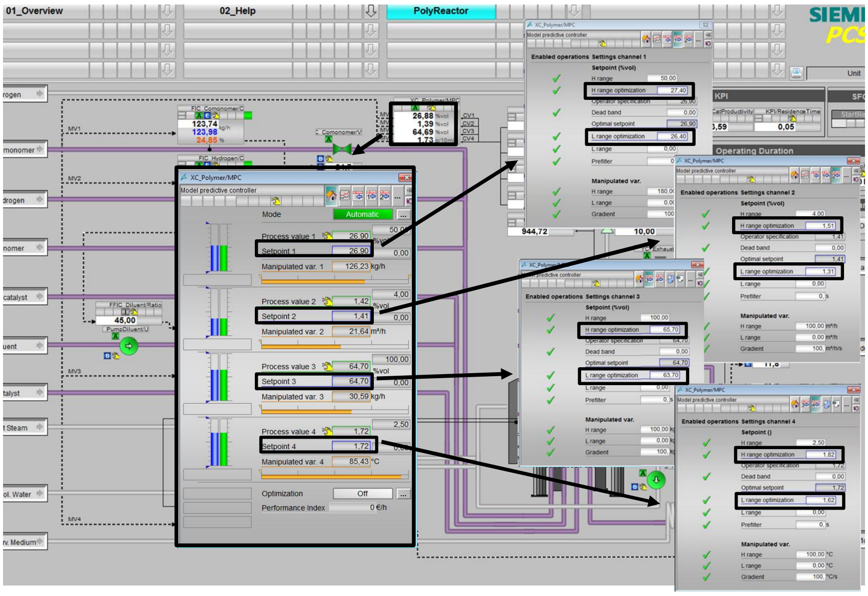
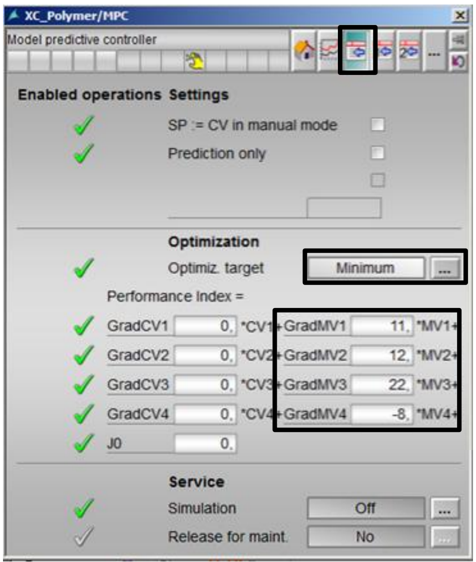
The minimization of costs is taken as a basis for the performance criterion.

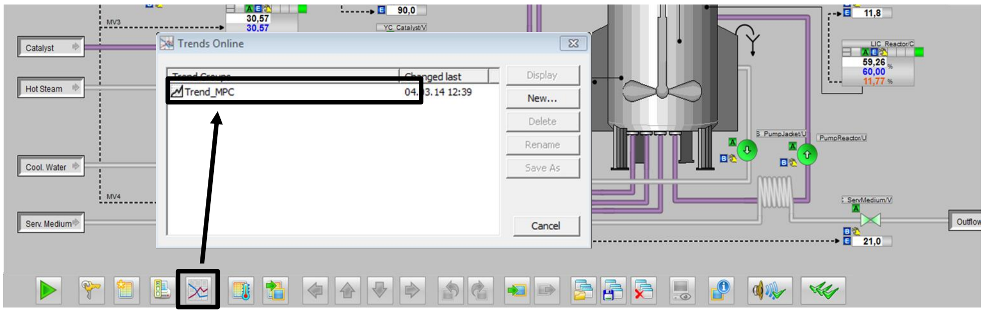
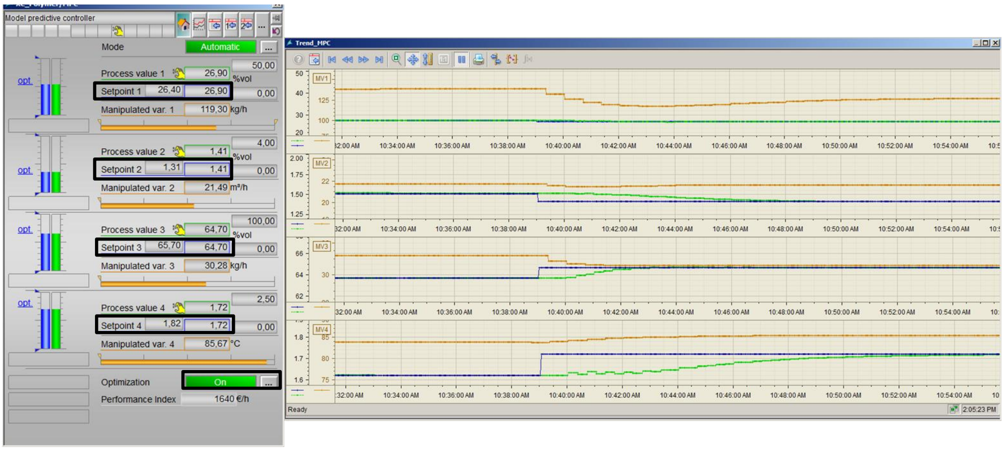
To this end, the following gradient for MV 1…4 is set:

- GradMV1 = 11
- GradMV2 = 12
- GradMV3 = 22
- GradMV4 = -8

Table 5-3

No.	Action
1.	In the OS, Switch to the process image of the polymerization reactor and wait until all operating points are reached and the controllers are enabled.

No.	Action
2.	Click on the module symbol of the "XC_Polymer" multivariable controller and verify the limit value settings for the optimization (parameter assignment) of all control variables. 
3.	For the optimization, set the gradients (weighting factors) for MV1 to MV4 with the optimization goal of cost minimization. 

No.	Action
4.	To monitor the MPC control, open the "Trend_MPC" trend display by means of the "Call up / consolidate curve groups" button.  **Note** The trend display can also be extended to other values, such as the current economic revenue from the performance criterion.
5.	To optimize, press the "Optimization" button and monitor the changes to the trend indicator. 
6.	After about 14 minutes, the operating point optimization is mostly completed.
7.	Stop the trend tracking in order to carry out an evaluation of the recorded data. For this purpose, you can also adjust the scaling of the time axis. **Note** The individual controller values (SPs, CVs and MVs) are archived, so that you can select your own time ranges in the trend indicator.

Evaluation

Figure 5–1 – Trend logging for the operating point optimization

After switching on the optimization, the MPC adopts the lower optimization limits for SP1 and SP2 and the upper optimization limits for SP 3 and SP4 as new setpoint values according to the weighting in the performance criterion.
All manipulated variables (MV) are passed on to the downstream controls as setpoint value specifications.
In terms of product quality, this means a higher MFI at lower concentrations.
A higher product temperature (MV4) is required for the higher MFI. For a higher product temperature, the downstream control itself requires less cooling water to be passed through the heat exchanger, which in turn may result in lower costs.

In this sample calculation, the operating point optimization can reduce costs by more than 10% from 1640 €/h to 1464 €/h with the adopted performance criteria.

Note

To perform an effective and meaningful optimization, it is necessary to provide the MPC with additional process-related technical data and limits, as well as basic economic information (revenues and costs). Costs or revenues, which do not have to depend on a constant factor of the manipulated or controlled variables of the MPC, must be calculated if required. This calculation of the economic data is to be carried out in a separate CFC and interconnected with the MPC.

You can find a good example of an economic operating point optimization in the example "Fluidized Bed Dryer - Design of Model Predictive Control with Economical Steady State Optimization" under the entry ID: 61926069 and the application example with integrated process simulation "PCS 7 Unit Template "Dryer" using the example of the Chemical Industry" under the entry ID: 74747848.

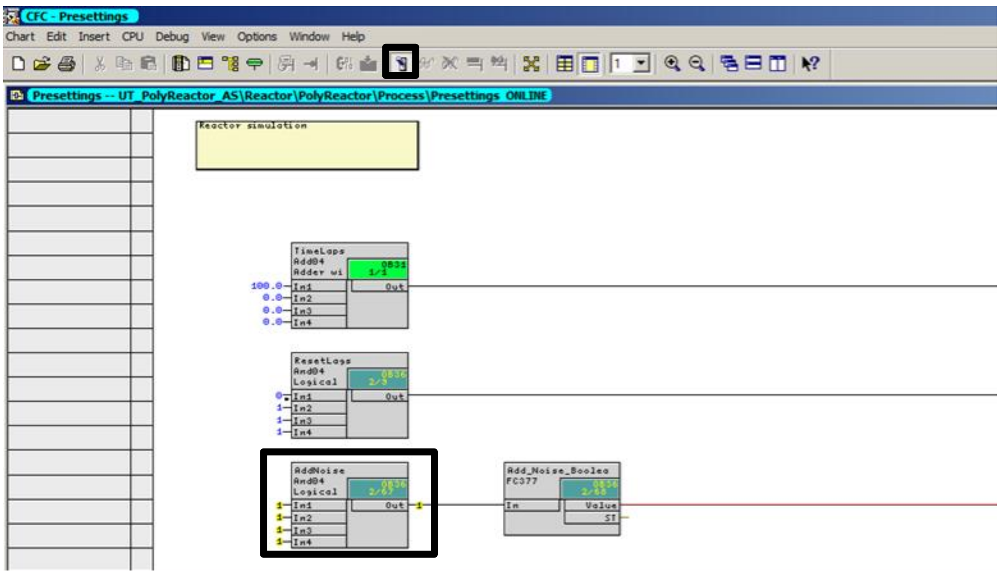
5.4 Scenario C – Monitoring the progress of the process with APG

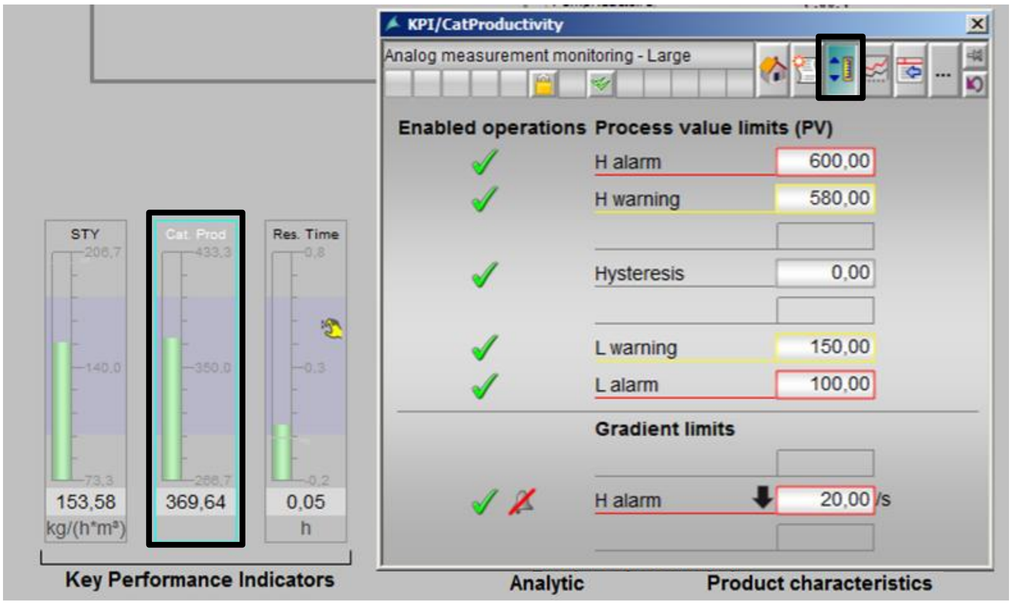
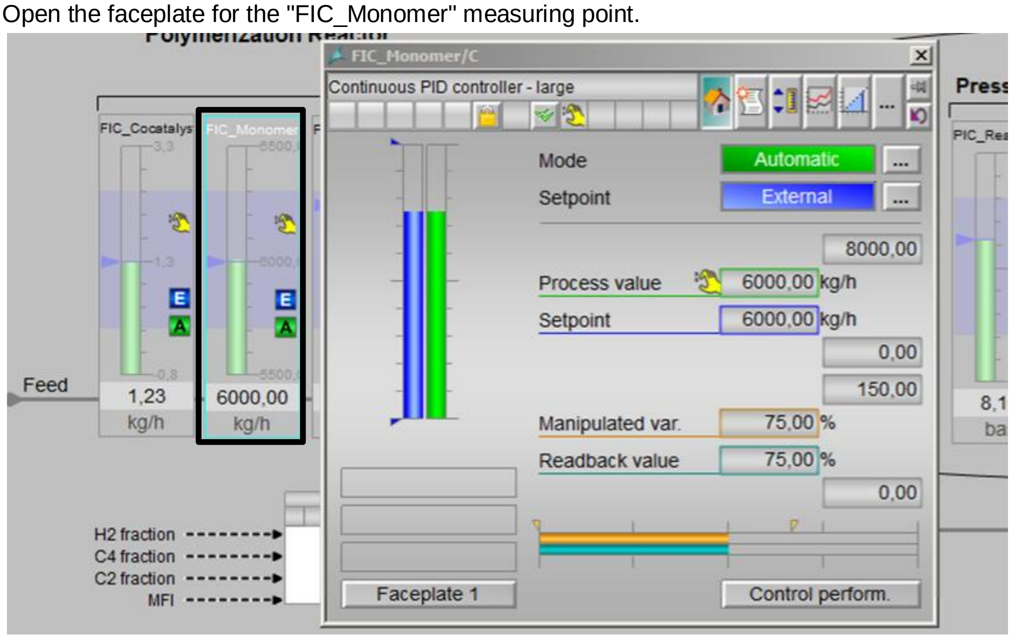
APG provides the plant operator with a rapid overview of all task-related process variables. Two process pictures of the polymerization reactor have been engineered with APG to demonstrate the functionality.

In this scenario, process noise is activated and limit values and infeeds are altered so that messages can be monitored in the two APG process pictures (Level 1 and Level 2).

Process noise for the jacket temperature and the reactor fill level is already activated when the plant is started up. Activating the noise on the "AddNoise" block provides a noise signal to the polymer density, melt flow index, H2 concentration, C4 concentration; C2 concentration and the polymer temperature. If you wish to set a stronger noise signal, you can set a larger value with the "StdDev"parameter in the noise blocks in the "Sim_Reactor" chart. Noise that is too great, e.g., when operating point optimization with a multi-variable controller is activated, has an influence on product quality as well as on control behavior. Depending on the deviation, it may be necessary to adjust the tolerance ranges for the operating points. If the fluctuations in several process variables are too great, the process will no longer be controllable.

Table 5-4

No.	Action
1.	Switch to the SIMATIC Manager plant view and openthe "Presettings" CFC in the path "UT_PolyReactor_MP > UT_PolyReactor_AS > Reactor > PolyReactor> Process > Presettings".
2.	Activate the test CPU from the "Debug > TestMode" menu item.
3.	Activate the display of all parameters in the "AddNoise" block and assign the value "1" to the "In1" parameter. 

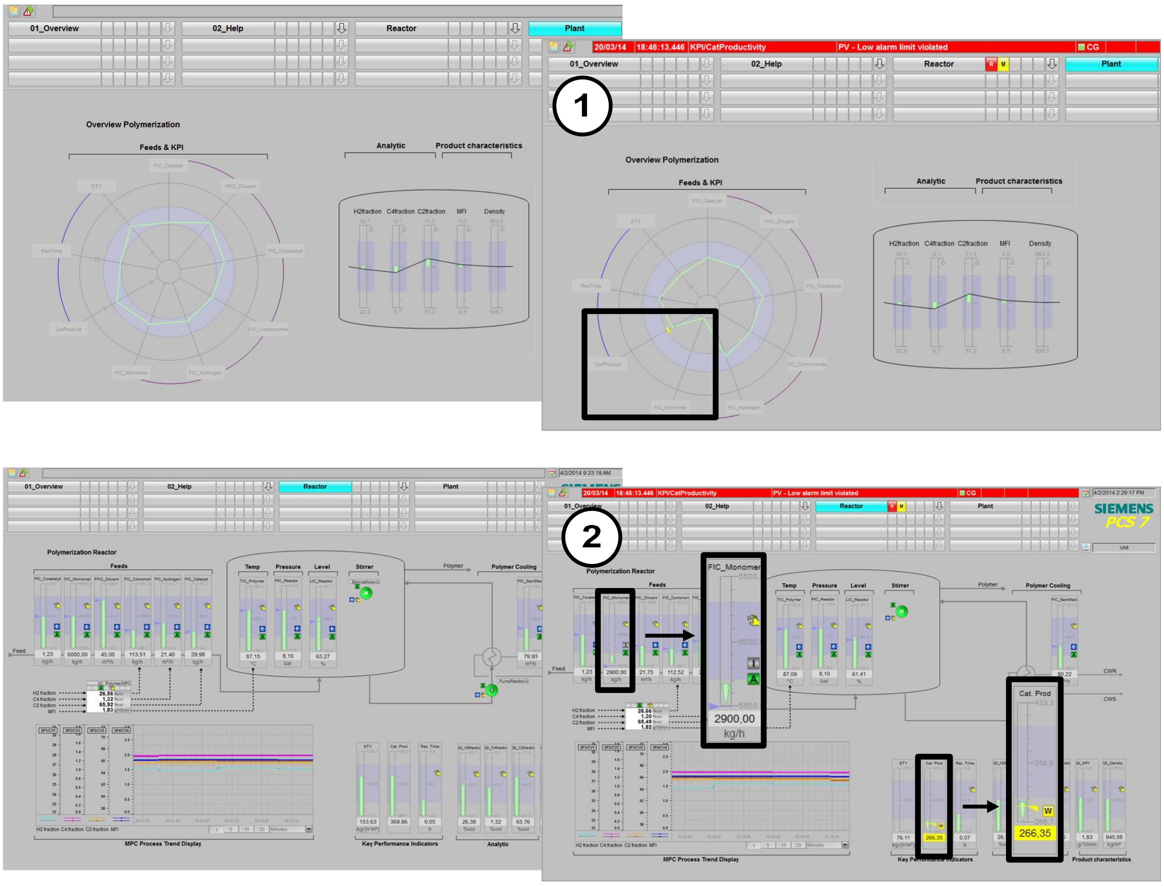
<table>
<tr><th>No.</th><th>Action</th></tr>
<tr><td>4.</td><td>In the OS, switch to the "Reactor" process picture and open the limit value settings in the faceplate for the "Cat. Prod" measuring point.

</td></tr>
<tr><td>5.</td><td>Set a lower lower warning limit of "290" and an alarm limit of "250".</td></tr>
<tr><td>6.</td><td>Open the faceplate for the "FIC_Monomer" measuring point.

</td></tr>
<tr><td>7.</td><td>Change the setpoint specification to internal and assign a new flow rate value of "2900".
Note
Even the flow rate of solvent (diluent) is reduced as it is supplied in proportion to the monomer.</td></tr>
</table>

Evaluation

By changing the flow volume, less monomer is supplied than is preset in the optimum working range. In addition, due to the ratio control even less solvent (diluent) is supplied to the reactor, which results in a temporary reduction in the fill level. The fill level controller corrects the disturbance variable with a lag. Due to the changed ratio of polymer density x polymer discharge to catalyst inflow, the level will be below the two set limits (alarm and warning) until the value settles in the region of "267", within the lower warning limit.

The following representation shows the changes to the two process pictures, "Reactor" and "Plant". The optimum process status can be seen on the left, while the effects of the inflow change can be recognized in the right hand process picture.

Figure 5-2



1. In the spider diagram in the "Plant" process picture, the effect of the catalyst productivity falling below the warning limit is represented by a yellow bar. Furthermore, from the polygon connection it can be recognized that the monomer flow rate is outside the working range.
2. In the "Reactor" process picture, the vertical green arrow pointing down indicates that the monomer flow rate has fallen below the display range. Alarm and warning limits are not set for the flow rates.
   The yellow measurement display, the yellow flashing "W" symbol and the yellow warning limit in the bar graph indicate that the catalyst productivity has fallen below the lower warning limit.

6 Literature

6.1 Related documents

This list is by no means complete and merely reflects a selection of suitable literature.

Table 6–1

	Subject area	Title
/1/	Practical manual for controllers with SIMATIC S7 and SIMATIC PCS7 for process automation	Controlling with SIMATIC Müller, Jürgen / Pfeiffer, Bernd-Markus / Wieser, Roland Publicis Kommunikationsagentur ISBN 978-3895783401

6.2 Internet links

Table 6-2

	Subject area	Title
\1\	Siemens Industry Online Support	https://support.industry.siemens.com/
\2\	Article download page	https://support.industry.siemens.com/cs/ww/en/view/84061788
\3\	SIMATIC PCS 7 overview (collection of links for FAQ, manuals, compendium, forum, application examples and videos)	https://support.industry.siemens.com/cs/ww/en/view/63481413
\4\	Controller optimization with the PID Tuner	https://support.industry.siemens.com/cs/ww/en/view/8031495
\5\	Equipment Modules for PCS 7 using the example of the Chemical Industry	https://support.industry.siemens.com/cs/ww/en/view/53843373
\6\	PCS 7 Unit Template "Stirred Tank Reactor" using the example of the Chemical industry	https://support.industry.siemens.com/cs/ww/en/view/60546560
\7\	PCS 7 Unit Template "Fermenter" using the example of the Chemical Industry	https://support.industry.siemens.com/cs/ww/en/view/68098270
\8\	PCS 7 Unit Template "Distillation Column" using the example of the Chemical Industry	https://support.industry.siemens.com/cs/ww/en/view/48418663
\9\	PCS 7 Unit Template "Dryer" using the example of the Chemical Industry	https://support.industry.siemens.com/cs/ww/en/view/74747848
\10\	How do you procure documentation for PCS 7 V8.0 (including the PCS 7 V8.0 Manual Collection)?	https://support.industry.siemens.com/cs/ww/en/view/59538371
\11\	Integration of Advanced Process Graphics in SIMATIC PCS 7	https://support.industry.siemens.com/cs/ww/en/view/89332241

7 History

Table 7–1

Version	Date	Change
V1.0	04/2014	First edition
V1.1	05/2014	New chapter 3.13 and 5.4 added
V1.2	09/2015	Update for PCS 7 V8.1