

# PCS 7 Unit Template "Steam Cracker" using the example of the chemical industry

SIMATIC PCS 7 V9.0 SP1

<https://support.industry.siemens.com/cs/ww/en/view/109769355>

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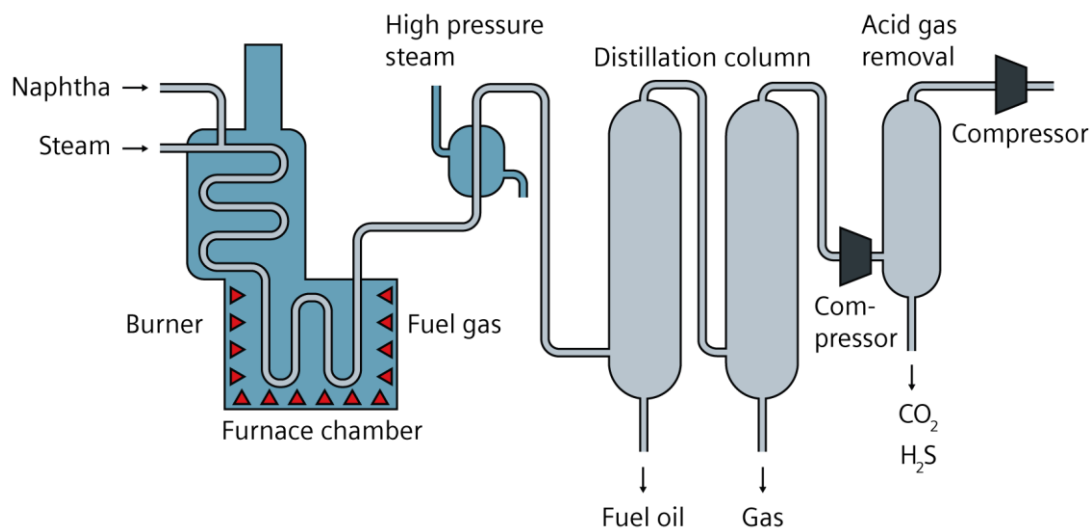
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# 1 Introduction

## 1.1 Overview

"Steam cracking" is a petrochemical process in which long-chain hydrocarbons (e.g. naphtha = petroleum) are converted into short-chain hydrocarbons by thermal cracking in the presence of steam. The main products produced are hydrogen, methane, ethylene and propene, butylene, pyrolysis gasoline and a tar-like residue (ECR: ethylene cracker residue). The raw materials obtained in this way are mainly used for the production of plastics, paints, solvents or pesticides.

The cracker plant is one of the most complicated plants in the petrochemical industry and can be divided into two large sub-processes: the cracker furnace itself and a downstream, multi-stage separation process consisting of distillation columns, steam separators and similar subsystems. The cracking furnace is a so-called tube reactor. The educt passes through the furnace simultaneously in many separate tube bundles with a small inner diameter of approx. 10 cm, so-called passes.



The Unit Template "Steam Cracker" contains prefabricated, standardized and ready-wired Equipment Modules and Control Module Types for the cracking furnace. Starting from this sample solution, numerous instances with different parameterizations can be generated and integrated into many automation solutions in an adapted form. The PCS 7 project is configured to be hardware-independent and can be flexibly incorporated into existing projects.

### Advantages

Its utilization offers the following advantages:

- A reduction of the knowledge necessary to develop applications
- A decrease in the configuration effort
- More flexible setup and adaptation due to equipment modules
- Standardized structures

## 1.2 Principle of operation

In cracking, an educt containing long-chain hydrocarbon molecules, e.g. naphtha, is preheated and then mixed with steam. The water-naphtha mixture is heated to a temperature of approx. 840°C in a coil of pipes. The long-chain molecules are thermally split within fractions of a second and a mixture of many substances with short-chain molecules is formed. The addition of water prevents the fission products from splitting further into even shorter-chain hydrocarbons.

The yield is of fundamental importance for the economic operation of a cracker. The main focus is on the yield of the two main products ethylene (C<sub>2</sub>H<sub>4</sub>) and propylene (C<sub>3</sub>H<sub>6</sub>).

In addition to the yield, the current intensity of the splitting process ("severity") plays a decisive role in the economic operation of a cracker. The severity quantifies the ratio of certain concentrations at the cracker outlet, for example the concentration of methane to propylene.

The material conversion of the long-chain hydrocarbons to the desired main products and the severity depend on many influencing factors and are therefore controlled by a corresponding multi-variable controller.

The required measurements of the yield or the intensity of the splitting process cannot be determined directly at the exit of the splitting furnace, but only summary and with a long delay at the downstream subsystems. To be able to respond to changes as quickly as possible directly in the cracker, the current value must be determined via a model-based soft sensor.

The tubes inside the furnace through which the educt/water vapor mixture flows consist of a special alloy which ensures that the best possible heat transfer to the material mixture is possible. In the long run (over several weeks) deposits on the pipes are increasing. This worsens the heat transfer between the outside and inside of the tubes. The current strength of the coking is also not measurable and must be estimated e.g. by a model. The yield of the cracker drops, depending on the degree of coking. If coking is too high, it is more profitable to switch off the system for cleaning. Along the pipes (length 60-80 meters) the degree of coking can vary considerably. Precise temperature measurement on the many pipes as basis for conventional control is very difficult to achieve.

A particular challenge is therefore to minimize coking. On the other hand, the current extent of coking must be reliably determined so that, if necessary, dates for cleaning can be planned.

In order to counteract the different coking of the pipes, an approach for a so-called "Pass Balancing" is required. It must be possible to optimize the flow of the reactants supplied and the temperature at the coil outlet ("coil outlet temperature") for each pass individually using a control concept. At the same time, the total throughput of converted educt must be maintained as well as possible.

### Delimitation

Typical designs for steam crackers have two combustion chambers at the lower end with typically 2 to 4 passes per combustion chamber. In this automation solution, all coils heated by a combustion chamber are represented by one coil.

In addition, only one of the two combustion chambers is implemented, the second half of the furnace can be created by duplicating the first half.

The thermal behavior of the entire furnace, with the heat capacities of the steel masses, is not taken into account, nor is the spatial expansion of the furnace chamber.

The process engineering process within the cracker furnace is only very simplified and simulated linearly in SIMIT respectively in SIMATIC PCS 7.

The necessary soft sensor for calculating the relevant measured variables has to simulate the dynamics of the gas phase reaction in the pipe coils as a realistic system with spatially distributed parameters. This requires a model of the system with coupled differential-algebraic equations. The number of equations in the "Steam Cracker" model is typically more than 50,000 equations and therefore cannot be simulated in SIMATIC PCS 7. For applications in real plants, the model-based soft sensor for each cracking furnace is implemented in PSE's simulation software gPROMS and connected to SIMATIC PCS 7 via OPC UA.

The Unit Template "Steam Cracker" contains a prefabricated solution for the cracker oven. The downstream, multi-stage separation process is not considered, since a Unit Template "distillation columns" \7\ is already available for the separation process.

The fail-safe implementation as well as a detailed description of the function and structure of the GARC is described in the PCS 7 Unit Template – Gas Fired Steam Boiler \9\.

### Required knowledge

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 Equipment Modules concept
- Basic knowledge with SIMIT

## 1.3 Components used

The following hardware and software components were used to create this application example:

Component	Note
SIMATIC PCS 7 ES/OS IPC547G W7	For the PCS 7 V9.0 SP1 example project
SIMATIC PCS 7 V9.0 SP1	Part of SIMATIC PCS 7 ES/OS IPC547G W7
APL library V9.0 SP1	Part of SIMATIC PCS 7 V9.0 SP1
CFC V9.0 SP2	License is a component of SIMATIC PCS 7 V9.0 SP1, the update can be obtained from the following link: <a href="https://support.industry.siemens.com/cs/ww/en/view/109756832">https://support.industry.siemens.com/cs/ww/en/view/109756832</a>
Software templates	Equipment Modules for SIMATIC PCS 7 using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/53843373">https://support.industry.siemens.com/cs/ww/en/view/53843373</a>
S7 PLCSIM (optional)	Not a part of SIMATIC PCS <sup>7</sup> V9.0 SP1, additional licenses required
SIMIT V10.0 (optional)	Not a part of SIMATIC PCS <sup>7</sup> V9.0 SP1, additional licenses required
Virtual Controller V10.0 (optional)	Not a part of SIMATIC PCS <sup>7</sup> V9.0 SP1, additional licenses required

### Note

If the hardware is different, observe the minimum requirements for installing the software components. The minimum requirements can be found in the PCS 7 Readme under the following link:  
<https://support.industry.siemens.com/cs/ww/en/view/109750097>.

This application example consists of the following components:

Component	Note
109769355_Steamcracker_DOC_PCS7_V90SP1_de.pdf	This document
109769355_Steamcracker_PROJ_PCS7_V90SP1.zip	PCS 7 V9.0 SP1 example project
109769355_Steamcracker_SIMIT_PCS7_V10.simarc	SIMIT V10.0 example project for PLCSIM
109769355_Steamcracker_SIMIT_VC_V10.simarc	SIMIT V10.0 example project for Virtual Controller

## 2 Preparation and commissioning

### 2.1 Choice of simulation type

The Unit Template has several options for simulating the steam cracking process, so that the simulation type can be selected for the demonstration of the Unit Template depending on the available license. The following simulation choices are available:

- PCS 7 with PLCSIM (process simulation in CFC)
- SIMIT with PLCSIM (process simulation in SIMIT)
- SIMIT with Virtual Controller (process simulation in SIMIT)

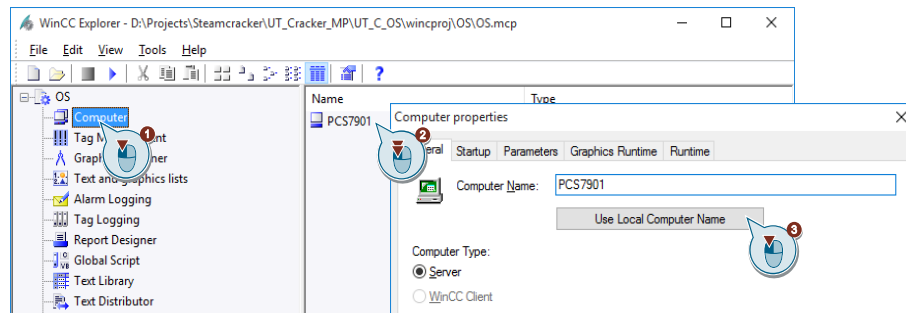
Depending on the simulation type, different steps must be performed to commission the Unit Template. The following table shows the necessary chapters for commissioning the Unit Template.

Chapter	PCS 7 with PLCSIM	SIMIT with PLCSIM	SIMIT with Virtual Controller
Preparation in PCS 7	X	X	X
Preparation in SIMIT with PLCSIM		X	
Preparation in SIMIT with Virtual Controller			X
Commissioning in PCS 7	X	X	
Commissioning in Virtual Controller			X
Activate the simulation with SIMIT		X	X

### 2.2 Preparation in PCS 7

The following instructions describe how to prepare the application example to be able to simulate the controller later. If a real controller is available, you must configure the hardware components in the HW configuration.

1. Copy the file "109769355\_Steamcracker\_PROJ\_PCS7\_V90SP1.zip" into any folder on the configuration computer and then open the SIMATIC manager.
2. Click on "File > Retrieve" in the menu bar and select the file "109769355\_Steamcracker\_PROJ\_PCS7\_V90SP1.zip". Then click "Open" to confirm.
3. Select the folder in which the project will be saved and confirm with the "OK" button.  
The project will be extracted.
4. Click the "OK" button in the "Retrieve" dialog and then click "Yes" in the dialog to open the project.
5. Right-click on "UT\_Cracker\_OS > OS01 > WinCC Appl. > OS" and click on the menu command "Open object".
6. Confirm the "Configured server is not available" dialog with "OK".
7. Open the properties of your computer in WinCC Explorer and click on the button "Use Local Computer Name" in the opened properties dialog.



8. Confirm the "Change computer name" message with "OK".
9. In WinCC Explorer, click "File > Exit" and in the subsequent dialog select "Terminate WinCC Explorer and close project".
10. Then confirm with "OK".

### 2.3 Preparation in SIMIT with PLCSIM

The following instructions describe the necessary preparation in SIMIT if the software PLCSIM is used for the emulation of AS:

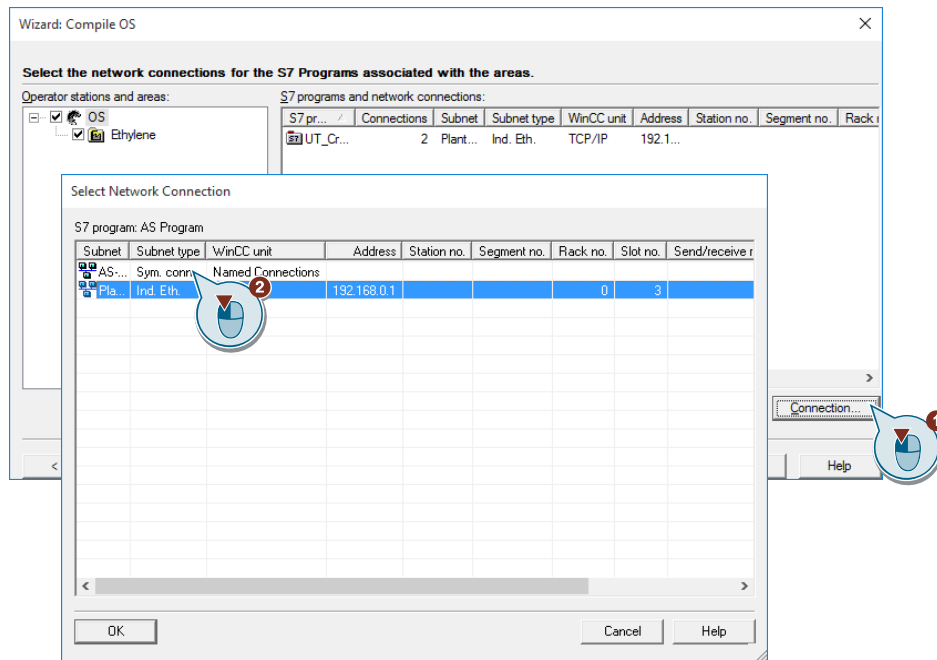
1. Copy the file "109769355\_Steamcracker\_SIMIT\_PCS7\_V10.simarc" into any folder on the configuration computer and then open SIMIT.
2. Select the menu item "Retrieve project".
3. Select the archived project in the "Archive name" field and click "Open" to confirm the dialog.
4. In the field "destination folder", select the path where you want to retrieve the SIMIT project and click "Open" to confirm the dialog.
5. Now click on the "Retrieve" button.
6. Change from the "Portal view" to the "Project view"
7. Start the simulation "Simulation > Start".  
In simulation mode, the color scheme from SIMIT changes to orange.

## 2.4 Preparation in SIMIT with Virtual Controller

The following instructions describe the necessary preparation in SIMIT if the software Virtual Controller is used for the emulation of AS:

### Preparation at the PCS 7 project

1. Right-click on "UT\_Cracker\_OS > OS01 > WinCC Appl. > OS" and click on the menu command "Compile".
2. Click on "Next".
3. Click on the "Connections" button and select "Named Connections."



4. Confirm the setting with "OK".
5. Compile the program with clicking on "Finish" and "Compile".

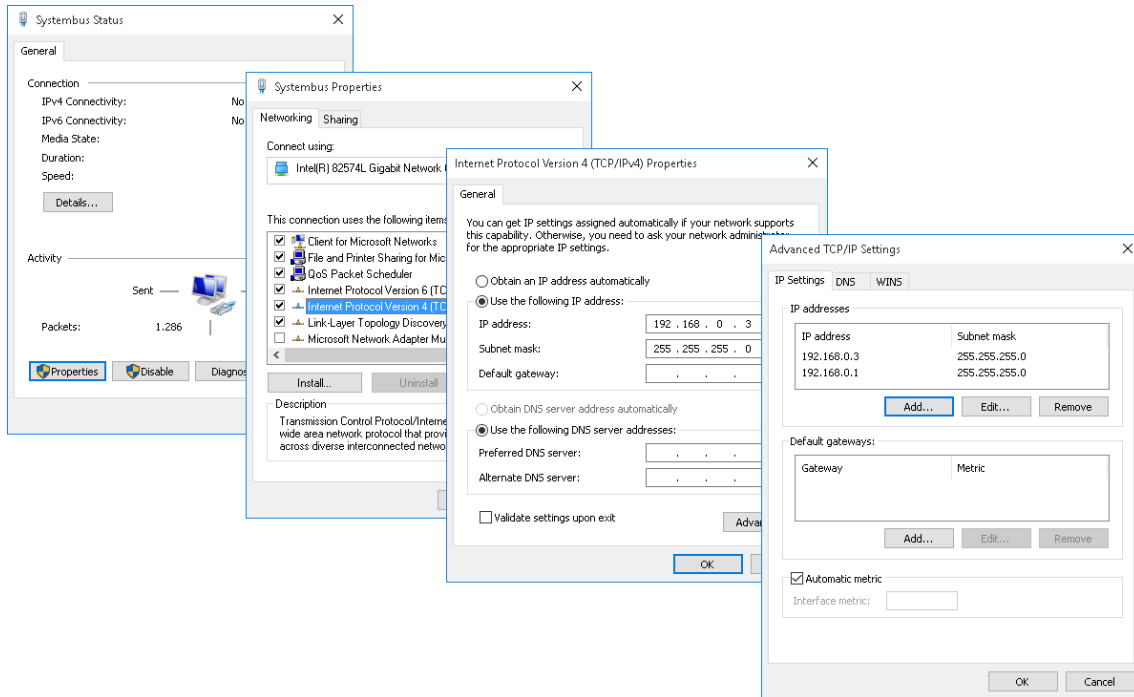
### Preparation of the PC Station

**NOTE** Communication with the Virtual Controller is network-based. For this reason, an additional IP address must be configured on the computer on which the VC is started.

1. Open the network settings of your engineering station.

## 2 Preparation and commissioning

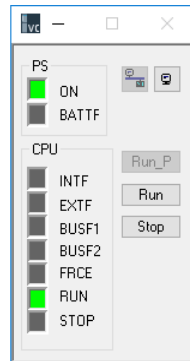
2. Enter an additional IP address for the VC in the properties of the "TCP / IPv4" interface. The IP address is the same as the configured AS in HW configuration (192.168.0.1).



### Starting the simulation (S7 PLCSIM)

1. Copy the file "109769355\_Steamcracker\_SIMIT\_VC\_V10.simarc" into any folder on the configuration computer and then open SIMIT.
2. Select the menu item "Retrieve project".
3. Select the archived project in the "Archive name" field and click "Open" to confirm the dialog.
4. In the field "destination folder", select the path where you want to retrieve the SIMIT project and click "Open" to confirm the dialog.
5. Now click on the "Retrieve" button.
6. Change from the "Portal view" to the "Project view"
7. Start the simulation "Simulation > Start".  
In simulation mode, the color scheme from SIMIT changes to orange.

- When the simulation is started in SIMIT, the virtual controller is also started.



## 2.5 Commissioning in PCS 7

The following instructions show how to initialize the Unit Template with PLCSIM. The project contains an SFC in which all important settings are configured so that the system reaches the operating point.

For commissioning it is assumed that the SIMATIC manager has already been opened and the Unit Template is selected in the component view.

### Starting the simulation (S7 PLCSIM)

To start the simulation, proceed as follows:

- Select "Options > Simulate Modules" from the menu. The "S7-PLCSIM" dialog window opens.
- Select the "Open PLC" option in the "File" dialog.
- Select the file "Steamcracker.plc" from the path <project path>\UT\_Cacker\_MP\UT\_C\_MP\Steamcracker.plc">. Simulation is started.
- In the selection list, change "PLCSIM(MPI)" to "PLCSIM(TCP/IP)".

### Activate OS runtime

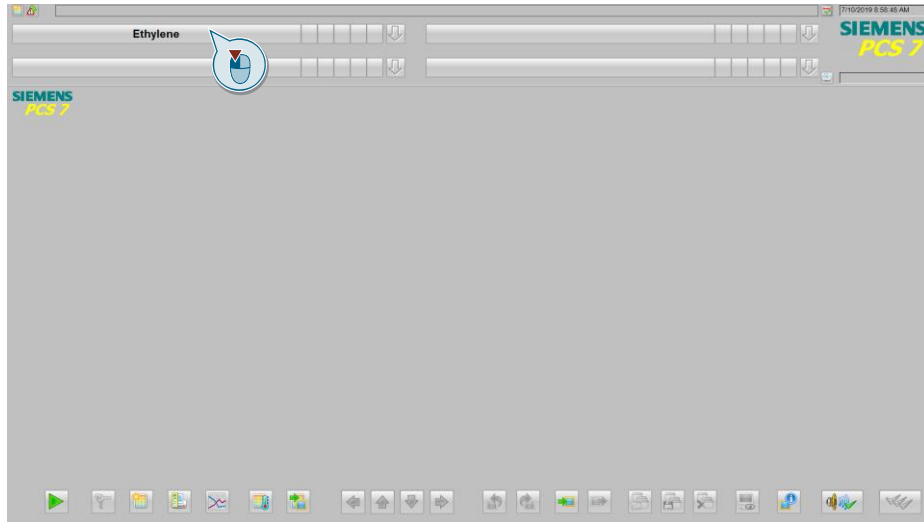
Proceed as follows to activate the OS Runtime:

- Right-click on "UT\_Cracker\_OS > OS01 > WinCC Appl. > OS" and click on the menu command "Open Object".
- Open the "Tag Management" by double-clicking it.
- In "WinCC Configuration Studio", open "Tag Management > SIMATIC S7 Protocol Suite > TCP/IP" and select "System parameters" in the context menu.
- In the register "Unit" check the set "Logical device name". When using the "S7-PLCSIM" program, "PLCSIM.TCPIP.1" is selected as the device name. A restart is required after a device name change.

#### Note

If the OS cannot establish a connection to the AS (gray block symbols), select the logical device name "CP\_H1\_1:" and restart the OS Runtime.

5. Select "File > Activate" in the WinCC Explorer menu.
6. Enter in the dialog "System Login" as "Login" the user "Unit" and as password "Template" and confirm with "OK".
7. Select "Ethylene" in the picture area



### Note

The steam cracker is already in the production process because the AS program execution (PLCSIM) has already been started.

## 2.6 Commissioning in Virtual Controller

The following instructions show how to initialize the Unit Template with PLCSIM. The project contains an SFC in which all important settings are configured so that the system reaches the operating point.

For commissioning it is assumed that the SIMATIC manager has already been opened and the Unit Template is selected in the component view.

### Download the software

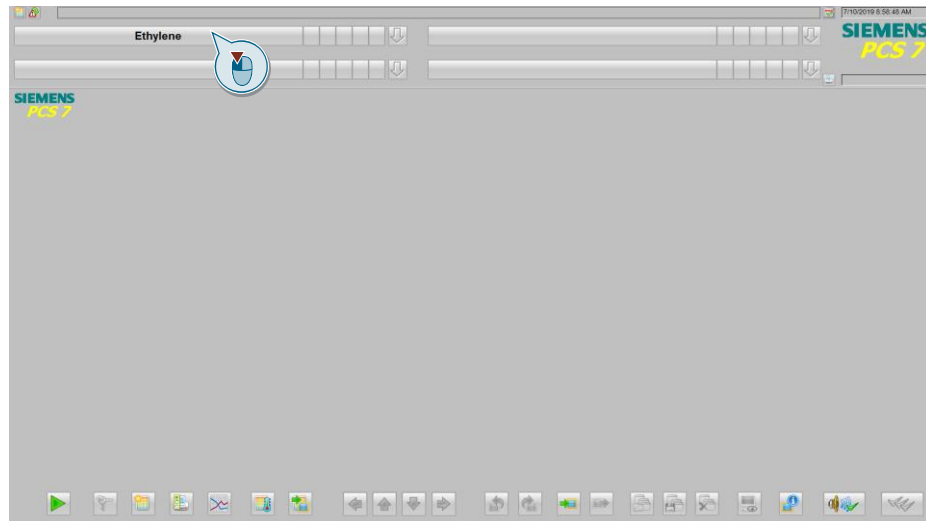
To start the simulation, proceed as follows:

1. Right-click on "UT\_Cracker\_OS> AS01" and click on the menu command "Open Object".  
The HW Config opens.
2. Click on "PLC > Download".
3. Select the option "Download in STOP mode" and confirm your entry with "OK".
4. Confirm the selection of the CPU and the address with "OK".
5. Open any CFC.
6. Click on "CPU > Download".
7. Select the option "Entire program" and confirm your entry with "OK".

### Activate OS runtime

Proceed as follows to activate the OS Runtime:

1. Right-click on "UT\_Cracker\_OS > OS01 > WinCC Appl. > OS" and click on the menu command "Open Object".
2. Select "File > Activate" in the WinCC Explorer menu.
3. Enter in the dialog "System Login" as "Login" the user "Unit" and as password "Template" and confirm with "OK".
4. Select "Ethylene" in the picture area



#### Note

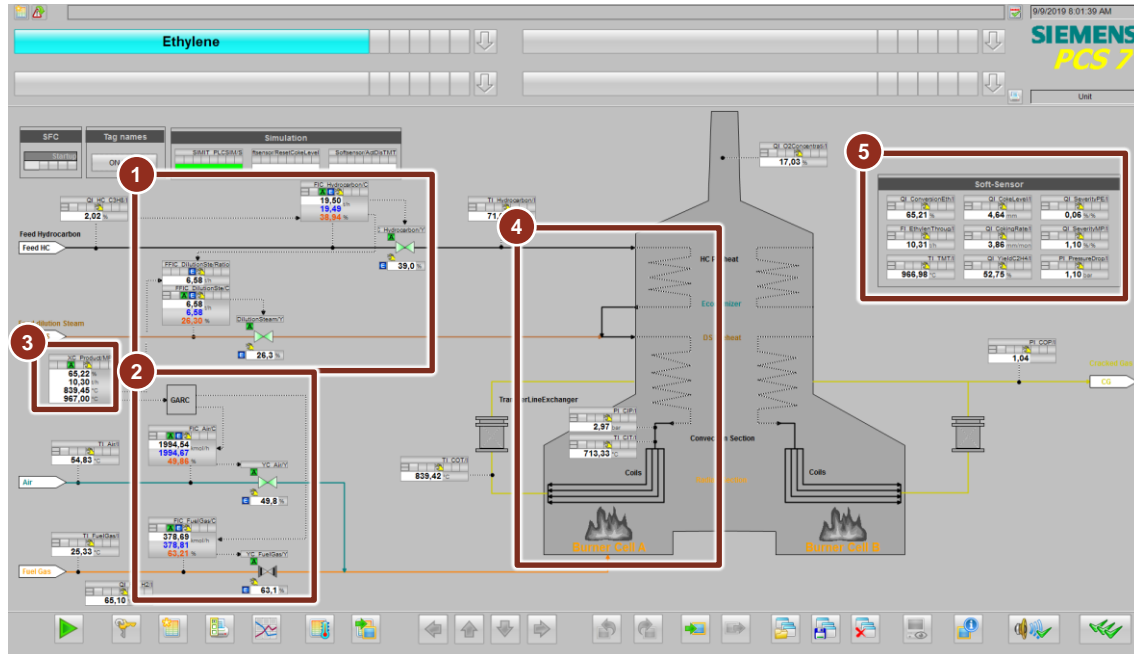
The steam cracker is already in the production process because the AS program execution (PLCSIM) has already been started.



## 3 Controlling the application

### 3.1 Components of process visualization

The figure below shows the process picture of the application example:



1. Inflow ("Feed")
2. Burner control ("Heating")
3. MPC
4. Furnace chamber ("Cracker")
5. Soft sensor

#### 1. Feed

The feed material educt and water are supplied in a defined mixing ratio via the inflow. The flow rate of the reactant is specified by the MPC via a setpoint and controlled by the flow controller via a proportional valve. After preheating of the reactant in the upper part of the cracking furnace, water vapor is mixed in a defined ratio, which is also controlled via a subordinate PID control loop with continuous valve. The ratio of water vapor to educt is specified by the MPC in a narrowly defined range (ratio from 0.30 to 0.35).

#### 2. Burner control (Heating)

A prerequisite for the chemical reactions is the correct temperature of the educt/water vapor mixture. In order to achieve a specified temperature inside the pass, the amount of gas and air in the burner is controlled by means of proportional valves. The burner is controlled via burner load specified by the MPC and the "Gas Air Ratio Controller (GARC)". The GARC calculates the required amount of gas and combustion air from the burner load, which is supplied in the correct stoichiometric ratio to the fuel. This ensures that a defined minimum excess of air is maintained in both stationary and dynamic operating conditions in order to guarantee a safe system condition. The GARC is part of the PCS 7 Unit Template Gas Fired Steam Boiler \9\.

### 3. MPC

The aim of the control is, on the one hand, to keep the quantity of ethylene and propylene produced as high as possible and, at the same time, to achieve a high conversion rate of the starting materials in order to keep scrap to a minimum. Production depends on many influencing factors and is therefore controlled by a corresponding multi-variable controller. The control variables selected are the throughput of the desired product and the conversion rate of the ethane added. In order to guarantee a safe system condition, the outlet temperature of the tube bundle (COT = Coil Outlet Temperature) and the tube wall temperature (TMT = Tube Metal Temperature) are kept within the tolerance band by the MPC as additional controlled variables. As soon as one of the two temperatures threatens to leave the tolerance range, they are considered by the MPC with high priority.

### 4. Furnace chamber ("Cracker")

The chemical reactions take place in the furnace chamber. The long-chain molecules are thermally split at the high temperature in fractions of a second, resulting in a mixture of many substances with shorter-chain molecules.

To heat the mixture, it passes through the furnace chamber of the cracking furnace in many separate tube bundles with a small inner diameter of approx. 10 cm, so-called passes. Typically, two to four coils (passes) pass through the furnace. The furnace in turn normally has two furnace chambers (Cells) at the lower end. In the furnace chamber, the coils separate into many smaller tubes with a diameter of approx. 10 cm, the coils. Here, the water vapor-educt mixture is split into short-chain molecules. The cracking furnace is a tube reactor.

### 5. Soft sensor

The ethane conversion rate and the ethylene yield are of decisive importance for process control. However, the material and reaction properties cannot be determined directly at the exit of the cracking furnace, but only with great delay at the downstream subsystems. An essential component of the Unit Template is therefore a soft sensor for calculating certain parameters including the ethane conversion rate and the ethylene yield, which are of decisive importance for process control. The soft sensor calculates the internal states of the steam cracker by simulating a dynamic process model and the input variables into the system in parallel. The subset of the system states corresponding to metrologically recorded variables are compared with the corresponding measured values of the real cracking process and used for online correction of the estimated states.

## 3.2 Scenarios

### 3.2.1 Overview

All components of the steam cracker can be operated and monitored via the process picture. In addition, the plant operator receives information (KPIs: Key Performance Indicators) on the current process status.

**Note** Please note that it takes about 3 minutes after the program start of PLCSIM until the steam cracker is at the operating point. During the running production operation, all controllers are enabled. You can recognize this state in the SFC, for example, if it has successfully processed all process steps.

The following two scenarios refer to the handling of the Unit Template "Steam Cracker":

- Compensation of coking
- Leaving the tolerance band for TMT

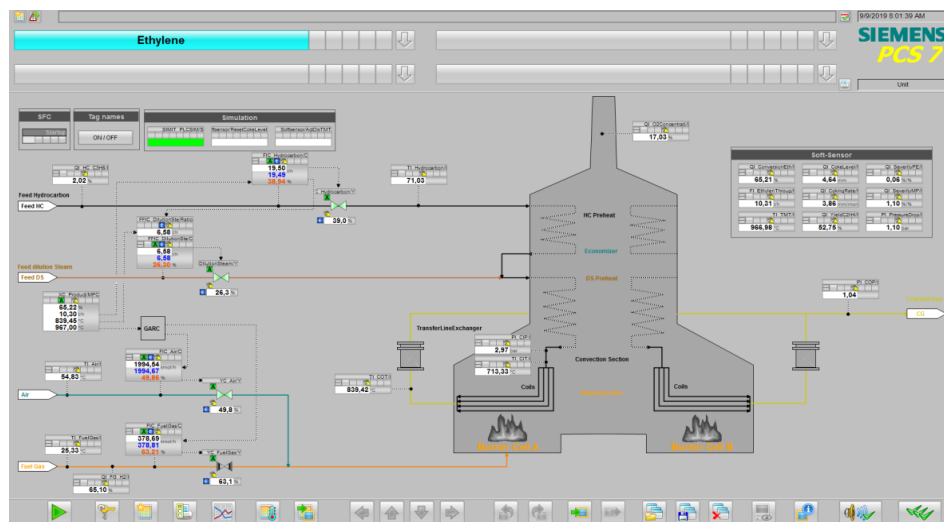
### 3.2.2 Scenario A - Compensation of coking

#### Description

In this scenario, the steam cracking process is simulated. A mixture of water vapor and educt is heated to temperatures of approx. 840°C within a pipe coil in the cracking furnace. The long-chain molecules are thermally split at the temperature in fractions of a second and a mixture of many substances with short-chain molecules is formed. In the long run, coking on the pipes are increasingly caused by the chemical reaction in the furnace. This worsens the heat transfer between the outside and inside of the tubes. In this scenario, the MPC automatically compensates for coking.

#### Procedure

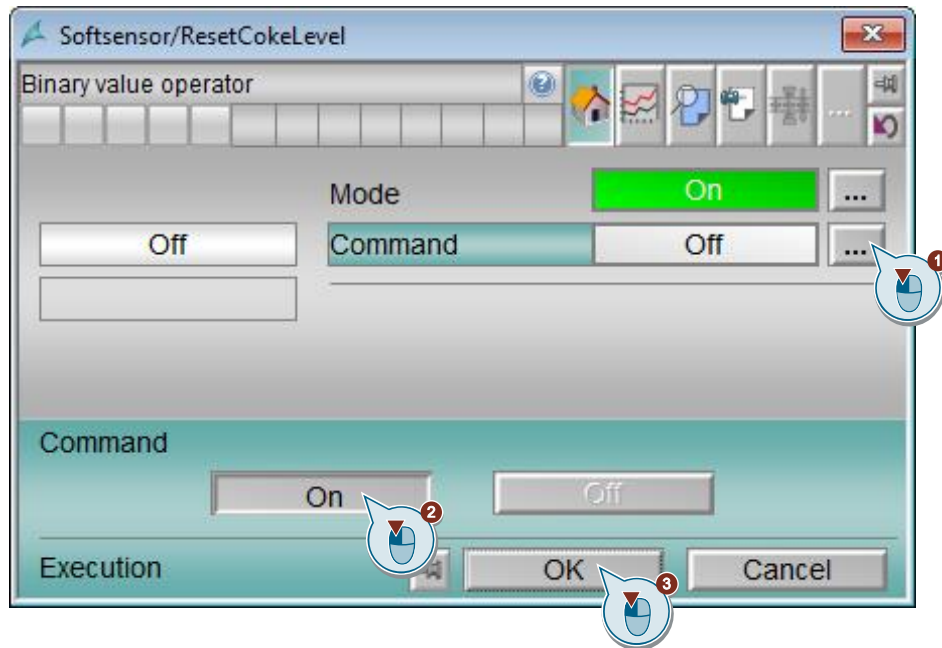
1. Open the process picture of the steam cracker.



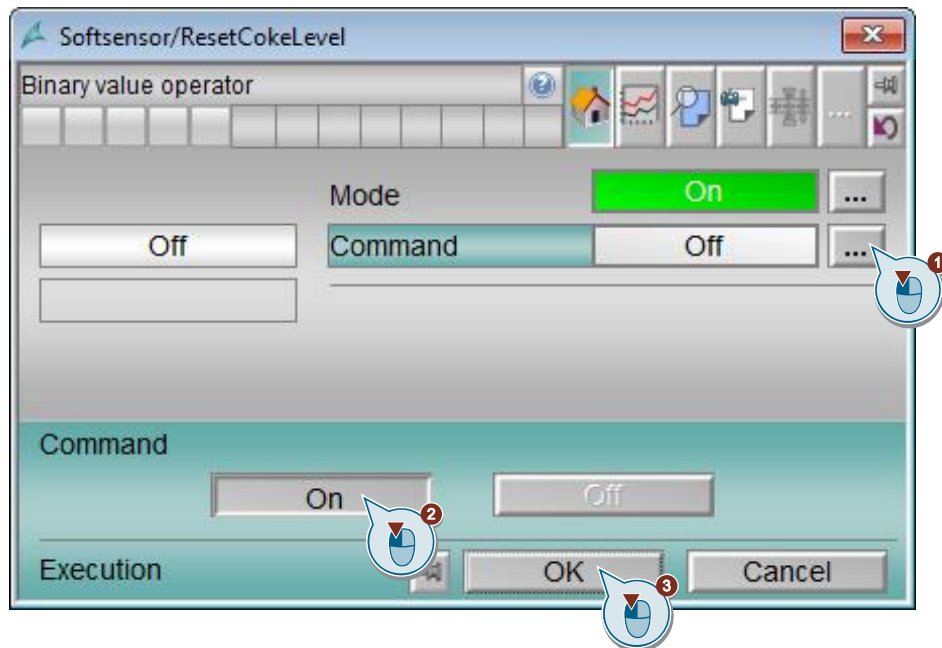
2. Left click the "On/Off" button in the "Tag name" field to display the block names.

### 3 Controlling the application

3. Click on the block symbol of the "Reset\_CokeLevel" block.  
The corresponding faceplate will be opened.



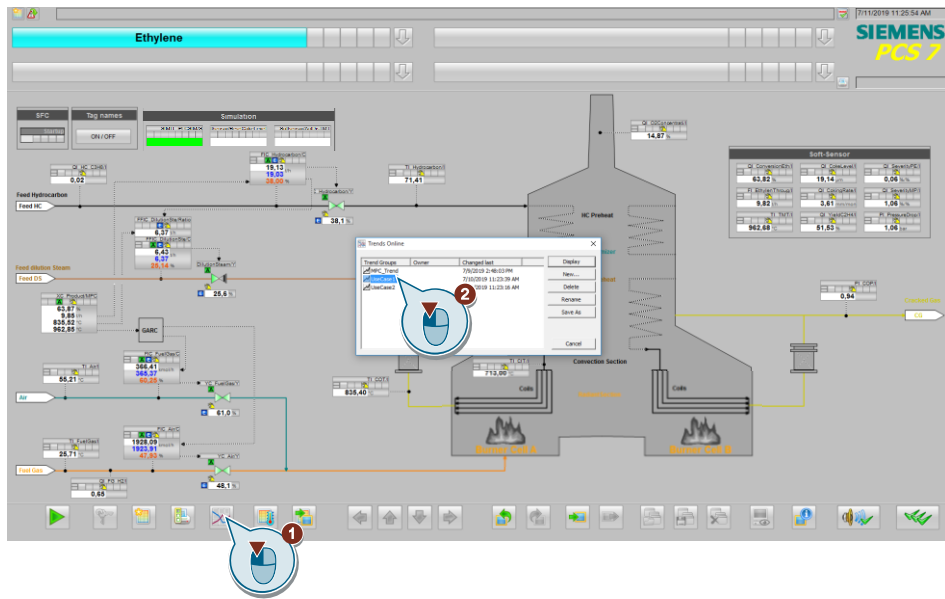
4. Click Command on the faceplate and select "On". Confirm your entry by clicking on "OK".



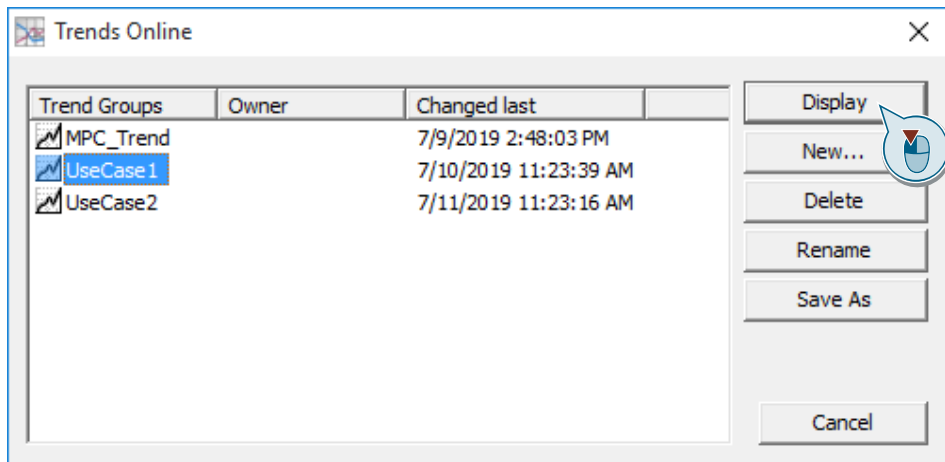
5. Click Command on the faceplate and select "Off". Confirm your entry by clicking on "OK".

### 3 Controlling the application

- Click on the button "trend system" and select the trend display "UseCase1".



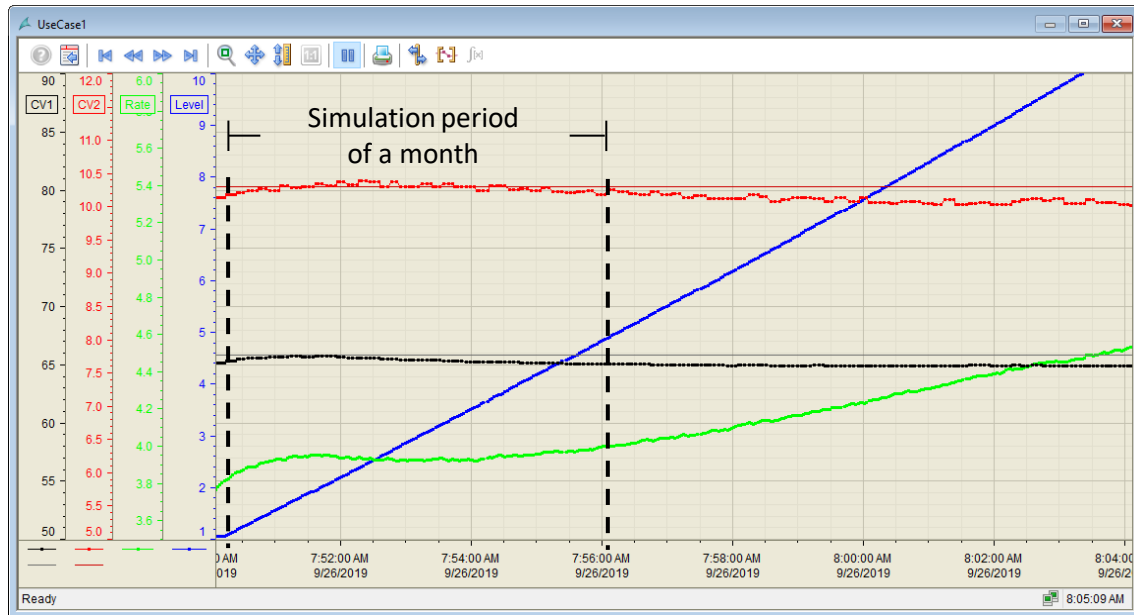
- Open the trend display by clicking on "Display".



- Wait approx. 12 minutes and click on the "Start/Stop" icon to evaluate the control result.

## Evaluation

The following figure shows the trend for the steam cracking process.



Due to the deposits on the pipes (blue line), the heat transfer between the outside and inside of the pipes deteriorates, this is shown in the trend over the blue line (thickness of the deposits) and green line (increase of the deposits). The deteriorate heat transfer leads to a reduction in the quantity of ethylene produced (red line) and conversion rate of the ethane supplied (black line). These deviations from the corresponding setpoint are compensated by the MPC by increasing the amount of energy supplied. As the result, the increase of the deposits over the operating period increases. During the simulation period of one month, the MPC can compensate for the disturbance caused by the coking process. With increasing duration, the control deviation becomes larger and larger until cleaning becomes necessary.

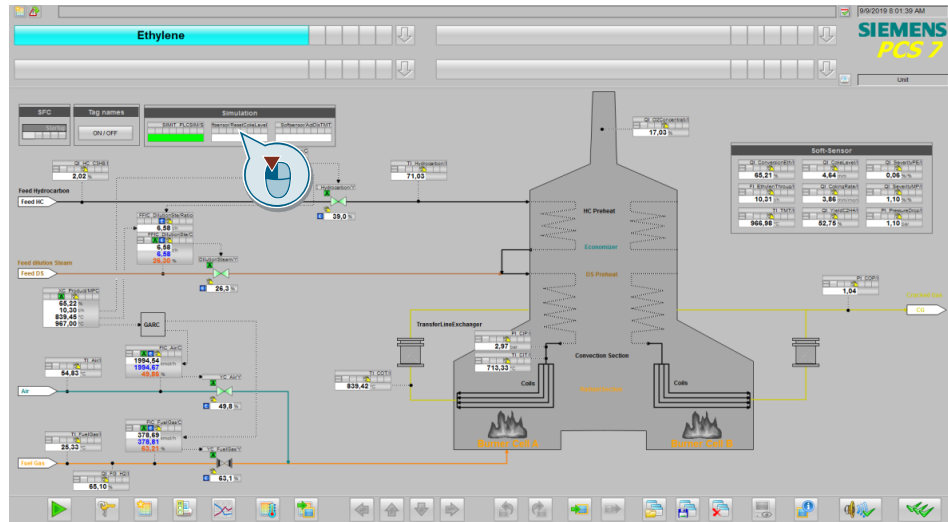
### 3.2.3 Scenario B - Leaving the tolerance band for TMT

#### Description

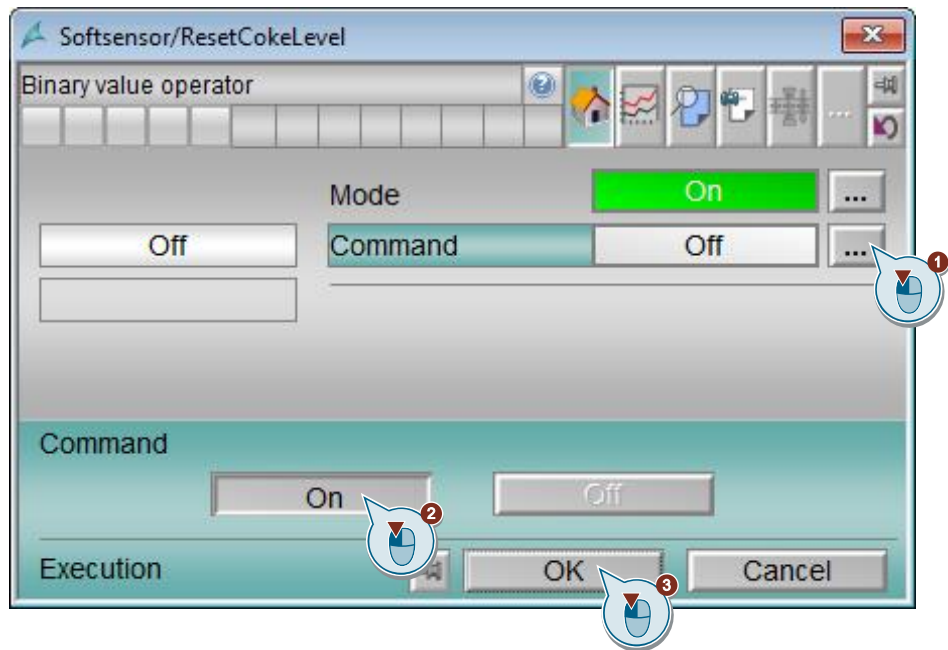
The aim of the control is, on the one hand, to keep the quantity of ethylene and propylene produced as high as possible and, at the same time, to achieve a high conversion rate of the starting materials. However, certain limits must not be exceeded in order to guarantee a safe system condition. In this scenario, a disturbance is added to the temperature TMT ("Tube Metal Temperature") so that the temperature leaves the tolerance band. The configuration of the MPC takes this process variable into account with high priority in order to ensure continued safe operation.

#### Procedure

1. Click on the block symbol of the "Reset\_CokeLevel" block. The corresponding faceplate will be opened.

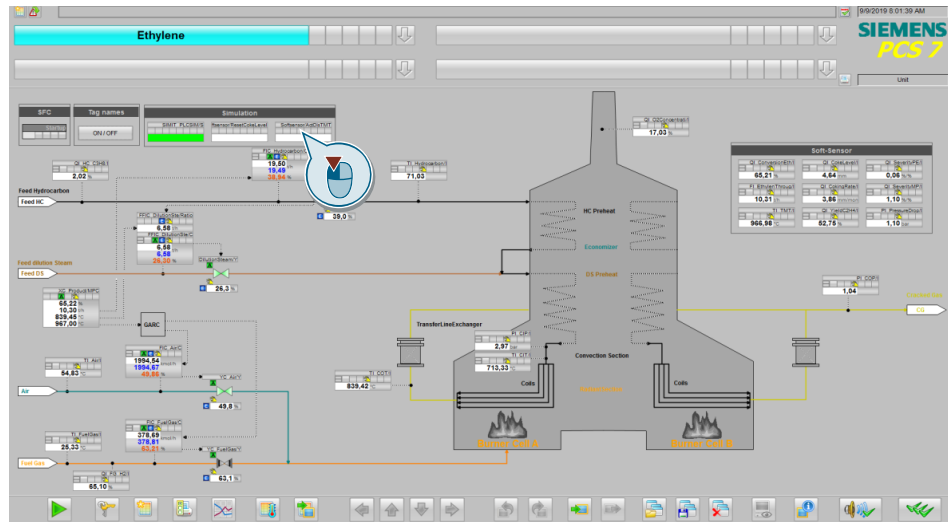


2. Click Command on the faceplate and select "On". Confirm your entry by clicking on "OK".

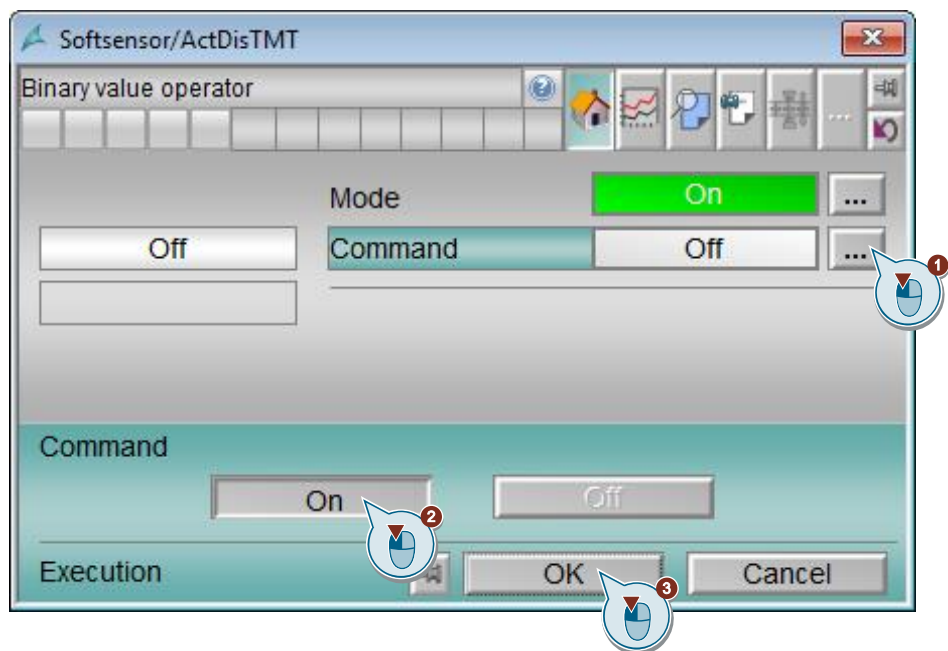


### 3 Controlling the application

3. Click on the block symbol of the "ActDisTMT" block.  
The corresponding faceplate will be opened.

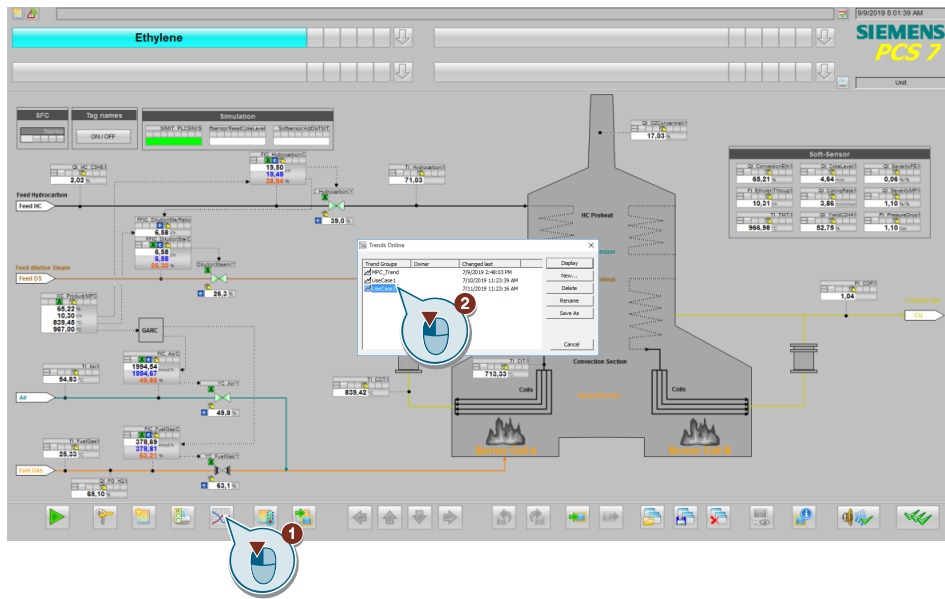


4. Click Command on the faceplate and select "On". Confirm your entry by clicking on "OK".

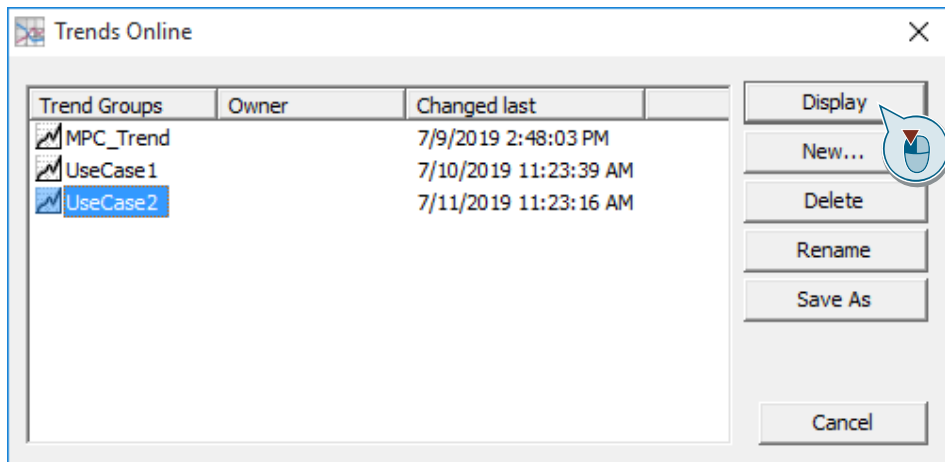


### 3 Controlling the application

5. Click on the button "trend system" and select the trend display "UseCase2".



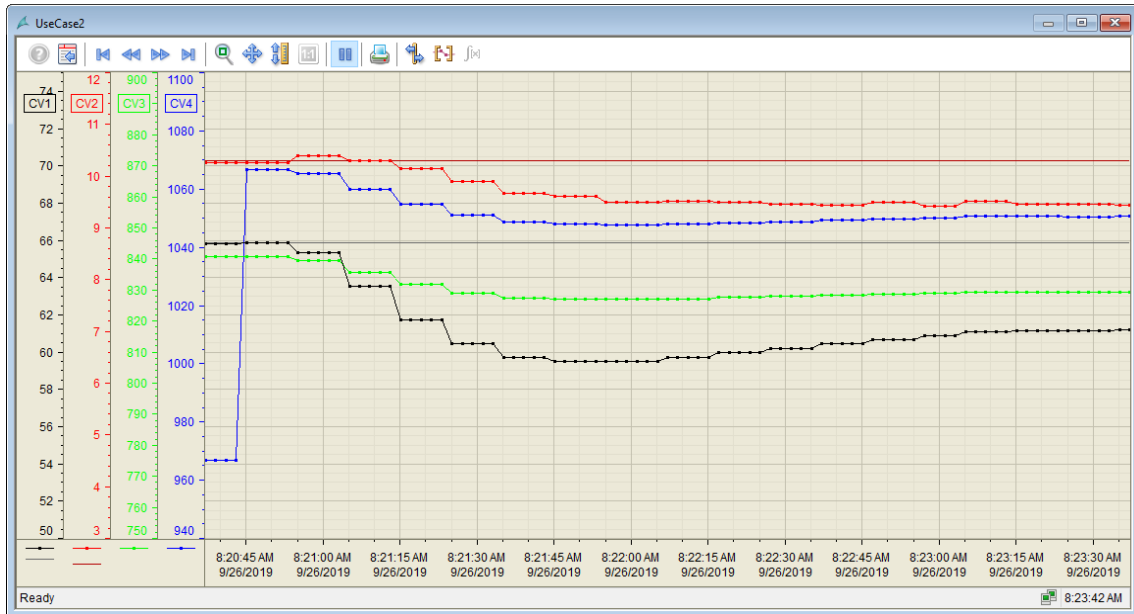
6. Open the trend display by clicking on "Display".



7. Wait about 3 minutes and click on the "Start/Stop" symbol to evaluate the control result.

**Evaluation**

The figure shows the trend curves of the multi-variable controller when the disturbance is added to the temperature TMT.



The temperatures COT ("Coil Outlet Temperature", green line) and TMT ("Tube Metal Temperature", blue line) must be kept within the tolerance range for safe operation of the system. Due to the limited number of degrees of freedom, the MPC was designed to control the amount of ethylene produced (red line) and the conversion rate of the starting materials (black line). The temperatures COT and TMT are kept within the respective tolerance band by the MPC. As soon as one of the two temperatures threatens to leave the tolerance range, these are considered by the MPC with high priority. Due to the setpoint change for the tube metal temperature, the process value leaves the tolerance band. This leads to the MPC giving high priority to bringing the temperature back into the tolerance band, but also to a significant reduction in the amount of ethylene produced and the conversion rate of ethane. Due to the limited number of degrees of freedom and the limitation of the tube metal temperature, the MPC cannot reach the target values for the quantity produced and the conversion rate. The MPC controls the system so that the tube metal temperature is maintained at the upper end of the tolerance band and the quantity produced and the conversion rate are as high as possible.

## 4 Integration of the Unit Template

### 4.1 Preparation

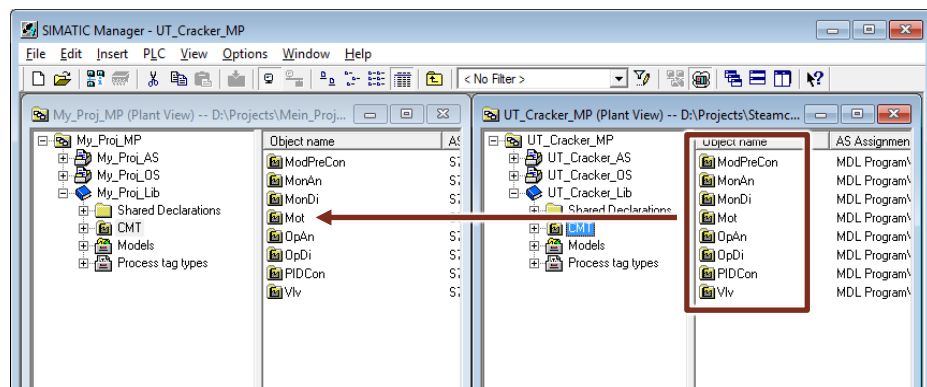
1. Copy the file "109769355\_Steamcracker\_PROJ\_PCS7V90SP1.zip" to the configuration computer and then open the SIMATIC manager.
2. Click on "File > Retrieve" in the menu bar and select the file "109769355\_Steamcracker\_PROJ\_PCS7\_V90SP1.zip". Then click "Open" to confirm.
3. Select the folder in which the project will be saved and confirm with the "OK" button.  
The project will be extracted.
4. Click the "OK" button in the "Retrieve" dialog and then click "Yes" in the dialog to open the project.
5. Switch to the "Plant view".
6. In parallel, open the project in which the Unit Template is to be integrated.

### 4.2 Copying templates

#### Note

If you have already worked with CMTs in your existing project, then check for equality before the following steps, as this can lead to errors in your existing project or the Unit Template to be integrated.

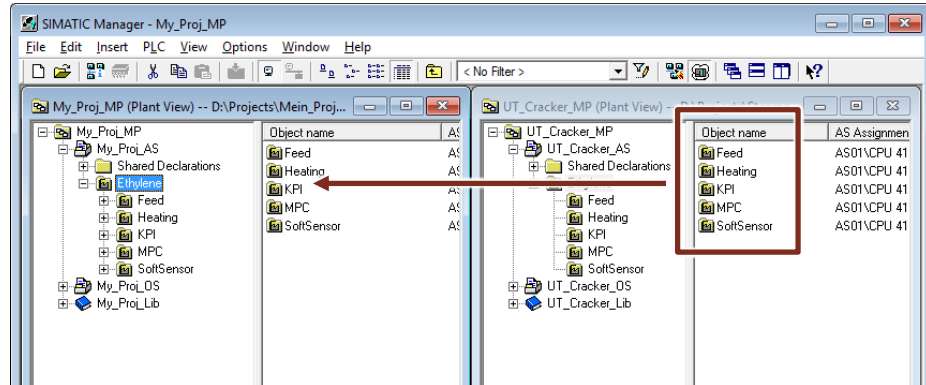
1. Go to the plant view.
2. Copy the "CMT" folder containing the CMTs from the master data library and paste it into the target project.



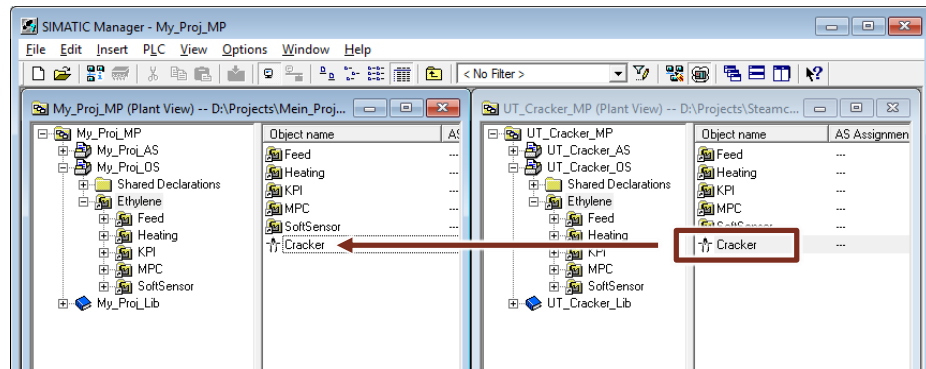
3. Copy the enumerations from the master data library and paste them into the target project.

### 4.3 Copying a plant section

1. Copy the hierarchy folder "Ethylene" from the AS project of the Unit Template into the plant hierarchy of the target project.



2. Copy the process picture "Cracker" from the OS project of the Unit Template also into the plant hierarchy of the target project.



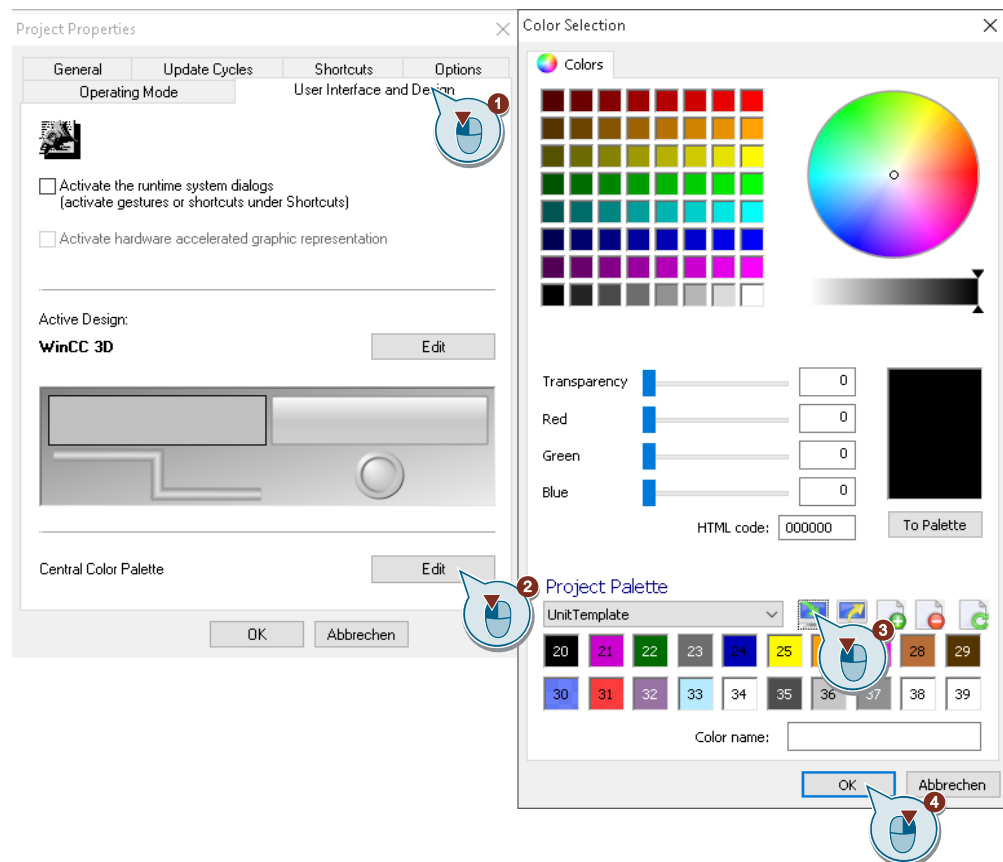
**Note** When copying the process picture, make sure that you copy the picture to the hierarchy level of the target project that is created as the OS area.

3. If you also want to use the customer-specific units in your project, copy the file "APLCustomerUnits.xml" from the directory "<Project path>\UT\_Cracker\_MP\UT\_C\_OS\wincproj\OS\GraCS\" into the GraCS folder of the target project.

## 4.4 Customizing the OS project

In order to be able to change the colors in the process picture of the steam cracker easily in a central place, a central color palette was created in the OS project of the Unit Template. To ensure that these colors are also displayed in the process picture of your own project, you must import the corresponding color palette.

1. In WinCC Explorer, select "OS" and select "Project Properties" from the context menu.
2. Select the "User Interface and Design" tab and click the "Edit" button.
3. Import the palette with the "Overwrite" option into your own project. The color palette is located in the project folder of the Unit Template under the path: "<Projektpfad>\UT\_Cracker\_MP\UT\_C\_OS\wincproj\OS\GraCS\UnitTemplate.xml". All existing colors will be replaced.



**Note** Note that all colors are always used when export/import color palettes. It is not possible to export individual color tables.

If you have created your own color tables in your project, you can also export these and merge the tables with an editor in the XML file. Alternatively, create a new color table in your project and project the colors individually. Also make sure that the color index does not change, otherwise you would have to adjust the color settings of the objects in the process picture. Of course, it is up to you to change the colors according to your requirements.

# 5 Engineering

## 5.1 Equipment Modules and Control Modules

The Unit Template "Steam Cracker" consists of ready-made Equipment Modules and additional CFC for e.g. the calculation of the gas and air volume for the burner. In the PCS 7 project, all Control Modules, as well as the Control Modules of the Equipment Modules, are based on CMTs (Control Module Type) of the master data library.

The application example "Steam Cracker" contains the following components:

- Inflow (Feed): Control of the educt-steam-mixture
- Burner control (Heating): Control of the burner
- MPC control of product properties
- Soft sensor (SoftSensor): Determination of non-measurable state variables
- Key Performance Indicators (KPI)
- Step chain (SFC) for starting the Unit Template
- Process simulation (Simulation)

### Note

All necessary descriptions, configurations and procedures pertaining to the

- design, functionality of equipment modules including parameters
- integration of equipment modules
- controllers and control response

can be found in the application description "Equipment Modules for SIMATIC PCS 7 using the example of the Chemical Industry" and the example projects with the equipment modules and CMTs at the following link: <https://support.industry.siemens.com/cs/ww/en/view/53843373> Information on the Equipment Modules can be found in the chapter "Equipment Modules" and on the CMTs in the chapter "Control Module".

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 Control Module Types. In addition, the SFC for starting the Unit Template "Steam Cracker" is documented.

### Note

CMTs are pre-configured for different operating ranges. The use of variants allows the corresponding channel block to be selected or deselected based on measured value transfer. It is also possible to use options to activate further functions without configuring the instance.

## 5.2 Inflow (Feed)

The inflow controls the amount of educt and water vapor, thereby heating the educt mixture in the upper part of the cracking furnace. After preheating of the reactant, water vapor is fed to the cracking furnace in a defined mixing ratio.

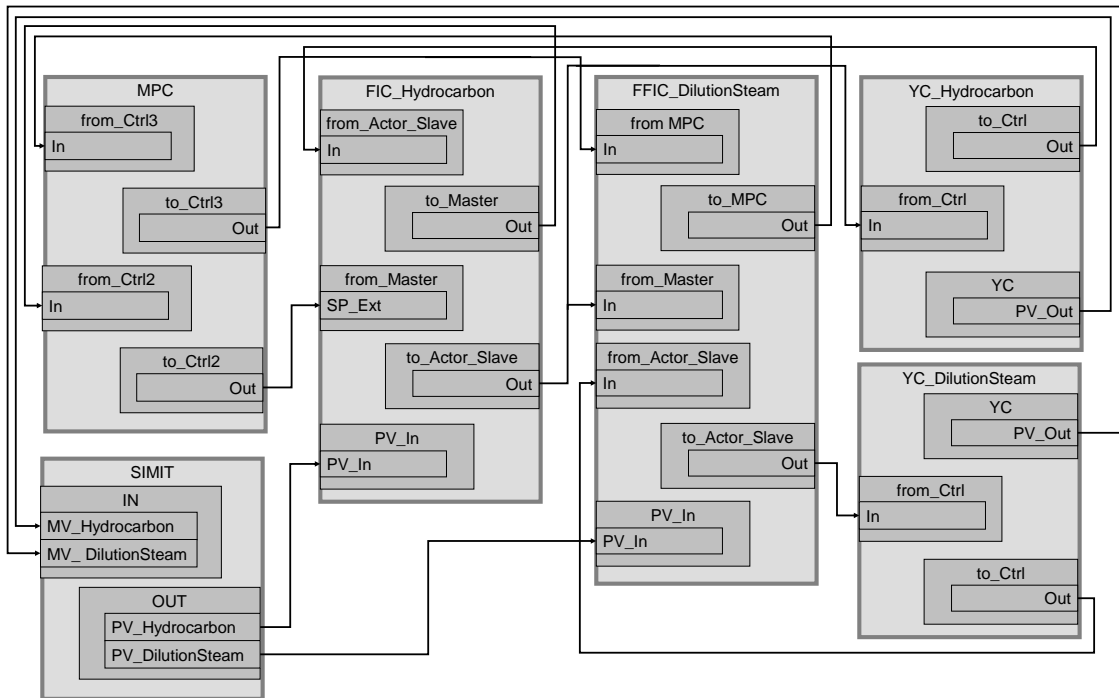
### 5.2.1 Setup

The flow rate of the reactant is specified by the MPC via a setpoint and controlled by the flow controller via a proportional valve. In a further step, water vapor is then mixed in a defined ratio to the educt, this ratio is regulated with a proportional valve. The ratio of water vapor to educt is also specified by the MPC in a narrowly defined range (ratio from 0.30 to 0.35).

The following table provides an overview of the components and control module types used.

CM	CMT	Selected variants	Description
FFIC_DilutionSteam	PIDConRatio	<ul style="list-style-type: none"> <li>• IF_Master</li> <li>• PV</li> <li>• PV_Scale</li> </ul>	Ratio flow controller for the inflow of steam
FIC_Hydrocarbon	PIDCon	<ul style="list-style-type: none"> <li>• IF_Master</li> <li>• PV</li> <li>• PV_Scale</li> </ul>	Flow controller for the inflow of the educt
YC_DilutionSteam	VlvAn	<ul style="list-style-type: none"> <li>• IF_Ctrl</li> <li>• GI</li> <li>• MV_Scale</li> <li>• YC</li> </ul>	Control valve for the inflow of water vapor
YC_Hydrocarbon	VlvAn	<ul style="list-style-type: none"> <li>• IF_Ctrl</li> <li>• GI</li> <li>• MV_Scale</li> <li>• YC</li> </ul>	Control valve for the inlet of the educt

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



### 5.2.2 Parameter assignment

#### FFIC\_DilutionSteam

With the Control Module "FFIC\_DilutionSteam" the addition of water vapor is recorded and controlled in relation to the educt. The setpoint is specified by the master controller "FIC\_Hydrocarbon", the ratio is specified by the MPC "XC\_Product" within a narrow range. The Control Module "FFIC\_DilutionSteam" transmits the output value to the valve Control Module "YC\_DilutionSteam". The Control Module "FFIC\_DilutionSteam" is an instance of the Control Module Type "PIDConRatio" and has been extended by an additional connection to the MPC to specify the relationship with the additional communication blocks.

The following table shows the project engineering of the instance.

Block	Connection	Value	Use
C	Gain	1.881	Controller gain
C	TI	9.119	Controller lag
C	PV_Out		Connection for KPI calculation (FI_ThroughputC2H4\Flow*Yield.In1)
to_Actor_Slave	Out		Connection to valve (YC_DilutionSteam\from_Ctrl.In)
from_Actor_Slave	In		Connection of the valve (YC_DilutionSteam\to_Ctrl.Out)
from_Master	In		Connection of the master controller (FIC_Hydrocarbon\to_Actor_Slave.Out)
to_MPC	ReStru1		Merging the wiring to the MPC (FFIC_DilutionSteam\Ratio.RatioPV)
to_MPC	BoStru1		Merging the wiring to the MPC (FFIC_DilutionSteam\Ratio.RatExtAc)

Block	Connection	Value	Use
to_MPC	Scale1.High Scale1.Low	0.5 0.25	Range limits for the ratio
to_MPC	Out		Connection to MPC (XC_Product\from_Ctrl3.In)
from_MPC	In		Connection from MPC (XC_Product\to_Ctrl3.In)
from_MPC	ReStru1		Merging the wiring to the MPC (FFIC_DilutionSteam\Ratio.RatioExt)
from_MPC	BoStru2		Merging the wiring to the MPC (FFIC_DilutionSteam\OosAct.In6)
Ratio	RatioPV		Output of the current ratio (FFIC_DilutionSteam\toMPC.ReStru1)
Ratio	RatExtAc		External specification of the ratio (FFIC_DilutionSteam\toMPC.BoStru1)
Ratio	RatExtLi	1	Activate external specification of the ratio
OosAct	In6		Merge Out of Service (FFIC_DilutionSteam\from_MPC.BoStru2)
PV_In	PV_In		Interconnection for the simulated process value (Process\Add_Noise_Diluti.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	25.0	Maximum value of the process value
PV_Unit	IN	1328	Unit of the process value (t/h)

### FIC\_Hydrocarbon

With the Control Module "FIC\_Hydrocarbon" the addition of the reactant is recorded and controlled. The setpoint is set by the MPC. The Control Module "FIC\_Hydrocarbon" transmits the controller output value to the valve Control Module "YC\_Hydrocarbon". The Control Module "FIC\_Hydrocarbon" is an instance from the Control Module Type "PIDCon".

The following table shows the project engineering of the instance.

Block	Connection	Value	Use
C	Gain	0.588	Controller gain
C	TI	6.142	Controller lag
C	PV_Out		Connection for KPI calculation (FI_ThroughputC2H4\Flow*Yield.In1)
to_Actor_Slave	Out		Connection to valve (YC_Hydrocarbon\from_Ctrl.In) (FFIC_DilutionSteam\from_Master.In)
from_Actor_Slave	In		Connection of the valve (YC_Hydrocarbon\to_Ctrl.Out)
to_Master	Out		Connection to MPC (XC_Product\from_Ctrl2.In)
from_Master	In		Connection from MPC (XC_Product\to_Ctrl2.Out)
PV	SimPV_In		Interconnection for the simulated process value (Process\Add_Noise_Hydroc.Out)

Block	Connection	Value	Use
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	50.0	Maximum value of the process value
PV_Scale	LoScale	1.0	Minimum value of the process value
PV_Unit	IN	1328	Unit of the process value (t/h)

### YC\_DilutionSteam

The valve Control Module "YC\_DilutionSteam" controls the supply of steam to the cracking furnace. The valve module receives the external setpoint via communication modules from the controller Control Module "FFIC\_DilutionSteam".

The following table shows the project engineering of the instance from "VlvAn".

Block	Connection	Value	Use
from_Ctrl			Interconnection for the controller (FFIC_DilutionSteam\from_Actor_Slave.Out)
to_Ctrl			Interconnection for the controller (FFIC_DilutionSteam\to_Actor_Slave.Out)
Y	MV		Interconnection for the simulation (Process\PT1_YC_DilutionS.In)
GI	SimPV_In		Connection of the simulation (Process\PT1_YC_DilutionS.Out)
GI	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)

### YC\_Hydrocarbon

The valve Control Module "YC\_Hydrocarbon" controls the flow of the reactant into the cracking furnace. The valve module receives the external setpoint via communication modules from the controller Control Module "FIC\_Hydrocarbon".

The following table shows the project engineering of the instance from "VlvAn".

Block	Connection	Value	Use
from_Ctrl			Interconnection for the controller (FIC_Hydrocarbon\from_Actor_Slave.Out)
to_Ctrl			Interconnection for the controller (FIC_Hydrocarbon\to_Actor_Slave.Out)
Y	MV		Interconnection for the simulation (Process\PT1_YC_Hydrocarb.In)
GI	SimPV_In		Connection of the simulation (Process\PT1_YC_Hydrocarb.Out)
GI	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)

## 5.3 Burner control (Heating)

For the chemical reactions, a temperature of the educt/water vapor mixture of approx. 840°C is required. The gas burner in the furnace chamber is controlled in order to achieve this predetermined temperature inside the coil.

### 5.3.1 Setup

The burner is controlled via a burner load specified by the MPC and the "Gas Air Ratio Controller (GARC)". The GARC calculates the required amount of gas and combustion air from the burner load, which is supplied in the correct stoichiometric ratio to the fuel. This ensures that a defined minimum excess of air is maintained in both stationary and dynamic operating conditions in order to guarantee a safe system condition. The GARC is part of the PCS 7 Unit Template – Gas Fired Steam Boiler \9\). The calculated quantity of gas and air from the burner is controlled by subordinate PID controllers with proportional valves.

The following table provides an overview of the components and control module types used.

CM	CMT	Selected variants	Description
FIC_Air	PIDCon	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> </ul>	Flow controller for the inflow of air into the burner
FIC_FuelGas	PIDCon	<ul style="list-style-type: none"> <li>• IF_Master</li> <li>• PV</li> <li>• PV_Scale</li> </ul>	Flow controller for the inflow of fuel gas
QI_O2Concentration	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> </ul>	Control Module for indication of the oxygen concentration
YC_Air	VlvAn	<ul style="list-style-type: none"> <li>• IF_Ctrl</li> <li>• GI</li> <li>• MV_Scale</li> <li>• YC</li> </ul>	Control valve for the inflow of air into the burner
YC_FuelGas	VlvAn	<ul style="list-style-type: none"> <li>• IF_Ctrl</li> <li>• GI</li> <li>• MV_Scale</li> <li>• YC</li> </ul>	Control valve for fuel gas inflow

In addition to the four CMTs mentioned above, the CFC "GARC" is used, which converts burner load to required quantity of gas and combustion air.

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



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### 5.3.2 Parameter assignment

#### FIC\_Air

The "FIC\_Air" Control Module is used to measure and regulate the air flow rate. The setpoint value for the air volume is set by the GARC. The Control Module "FIC\_Air" transmits the controller output value to the valve Control Module "YC\_Air". The measurement loop "FIC\_Air" is an instance from the Control Module Type "PIDCon".

The following table shows the project engineering of the instance.

Block	Connection	Value	Use
C	Gain	1.88	Controller gain
C	Tl	7.282	Controller lag
C	PV_Out		Connection to GARC (GARC\GARC_SP.AIR)
C	SP_InHiL	4000.0	Upper limit of the internal setpoint

Block	Connection	Value	Use
to_Actor_Slave	Out		Connection for the valve (YC_Air\from_Ctrl.In)
from_Actor_Slave	In		Connection to valve (YC_Air\to_Ctrl.Out)
PV	SimPV_In		Interconnection for the simulated process value (Process\Add_Noise_Air.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	4000.0	Maximum value of the process value
PV_Unit	IN	4	Unit of the process value (kmol/h)

### FIC\_FuelGas

With the Control Module "FIC\_FuelGas" the inflow of the fuel gas is recorded and controlled. The setpoint for the amount of fuel gas is also set by the GARC. The Control Module "FIC\_FuelGas" transmits the controller output value to the valve Control Module "YC\_FuelGas". The Control Module "FIC\_FuelGas" is an instance from the Control Module Type "PIDCon".

The following table shows the project engineering of the instance.

Block	Connection	Value	Use
C	Gain	4.121	Controller gain
C	TI	9.989	Controller lag
C	PV_Out		Connection to GARC (GARC\GARC_SP.AIR)
C	SP_InHiL	600.0	Upper limit of the internal setpoint
to_Actor_Slave	Out		Connection for the valve (YC_FuelGas\from_Ctrl.In)
from_Actor_Slave	In		Connection to valve (YC_FuelGas\to_Ctrl.Out)
PV	SimPV_In		Interconnection for the simulated process value (Process\Add_Noise_FuelGa.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	600.0	Maximum value of the process value
PV_Unit	IN	4	Unit of the process value (kmol/h)

### GARC

The "GARC" Control Module calculates the setpoints for the "FIC\_FuelGas" and "FIC\_Air" controllers from the MPC burner load output value. This ensures that a defined minimum excess of air is maintained in both stationary and dynamic operating conditions in order to guarantee a safe system condition.

Usually, the control of a burner is implemented with additional error protection measures, such as fail-safe components from the F-System area. The fail-safe implementation as well as a detailed description of the function and structure of the GARC can be found in the PCS 7 Unit Template – Gas Fired Steam Boiler \9).

The following table shows the connection of the Control Module from "GARC".

Block	Connection	Value	Use
LOAD_TO_01	In1		Setpoint specification of MPC (XC_Product\from_Master.Out)
GARC_SP	GAS		Actual value of the flow to burner gas (FIC_FuelGas\C.PV_Out)
GARC_SP	AIR		Actual value of the flow to burner gas (FIC_Air\C.PV_Out)
GARC_SP	SP_GAS		Actual value of the flow to burner gas (FIC_FuelGas\AIF_SFC.SP_Ext)
GARC_SP	SP_AIR		Actual value of the flow to burner gas (FIC_Air\AIF_SFC.SP_Ext)

### QI\_O2Concentration

The display Control Module "QI\_O2Concentration" visualizes the amount of remaining oxygen after combustion.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Process\Noise_QI_O2.Noise)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	21.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1342	Process value unit (%)
To_Indicate	Out		Connection to the controlled variable of the multi-variable controller (XC_Product\from_CV4.In)

### YC\_Air

The valve Control Module "YC\_Air" controls the air flow into the burner. The valve module receives the external setpoint via communication modules from the controller Control Module "FIC\_Air".

The following table shows the project engineering of the instance from "VlvAn".

Block	Connection	Value	Use
from_Ctrl			Interconnection for the controller (FIC_Air\from_Actor_Slave.Out)
to_Ctrl			Interconnection for the controller (FIC_Air\to_Actor_Slave.Out)
Y	MV		Interconnection for the simulation (Process\PT1_YC_Air.In)
GI	SimPV_In		Connection of the simulation (Process\PT1_YC_Air.Out)
GI	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)

**YC\_FuelGas**

The valve Control Module "YC\_FuelGas" controls the fuel gas into the burner. The valve module receives the external setpoint via communication modules from the controller Control Module "FIC\_FuelGas".

The following table shows the project engineering of the instance from "VlvAn".

Block	Connection	Value	Use
from_Ctrl			Interconnection for the controller (FIC_FuelGas\from_Actor_Slave.Out)
to_Ctrl			Interconnection for the controller (FIC_FuelGas\to_Actor_Slave.Out)
Y	MV		Interconnection for the simulation (Process\PT1_YC_FuelGas.In)
GI	SimPV_In		Connection of the simulation (Process\PT1_YC_FuelGas.Out)
GI	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)

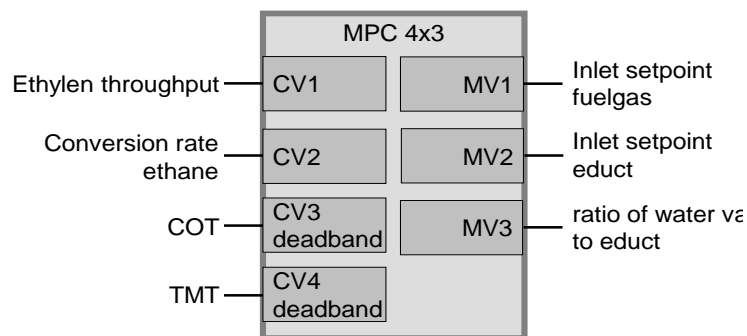
## 5.4 MPC

The aim of the control is, on the one hand, to keep the quantity of ethylene and propylene produced as high as possible and, at the same time, to achieve a high conversion rate of the starting materials. The material conversion of the long-chain hydrocarbons to the desired main products depends on many influencing factors and is therefore controlled by a corresponding multi-variable control concept.

The overall tasks of the MPC are as follows:

- **Production quantity:** Drive ethylene throughput to defined setpoint
- **Product quality:** Keep conversion rate of ethane (measure for "Severity") on target value
- **Limit coking:** keep COT ("Coil Outlet Temperature") in specified range
- **Safe plant operation:** Keep TMT ("Tube Metal Temperature") below critical upper limit
- Find a **suitable setpoint combination** for the inlet of the duct, process steam and fuel gas.

### 5.4.1 Setup



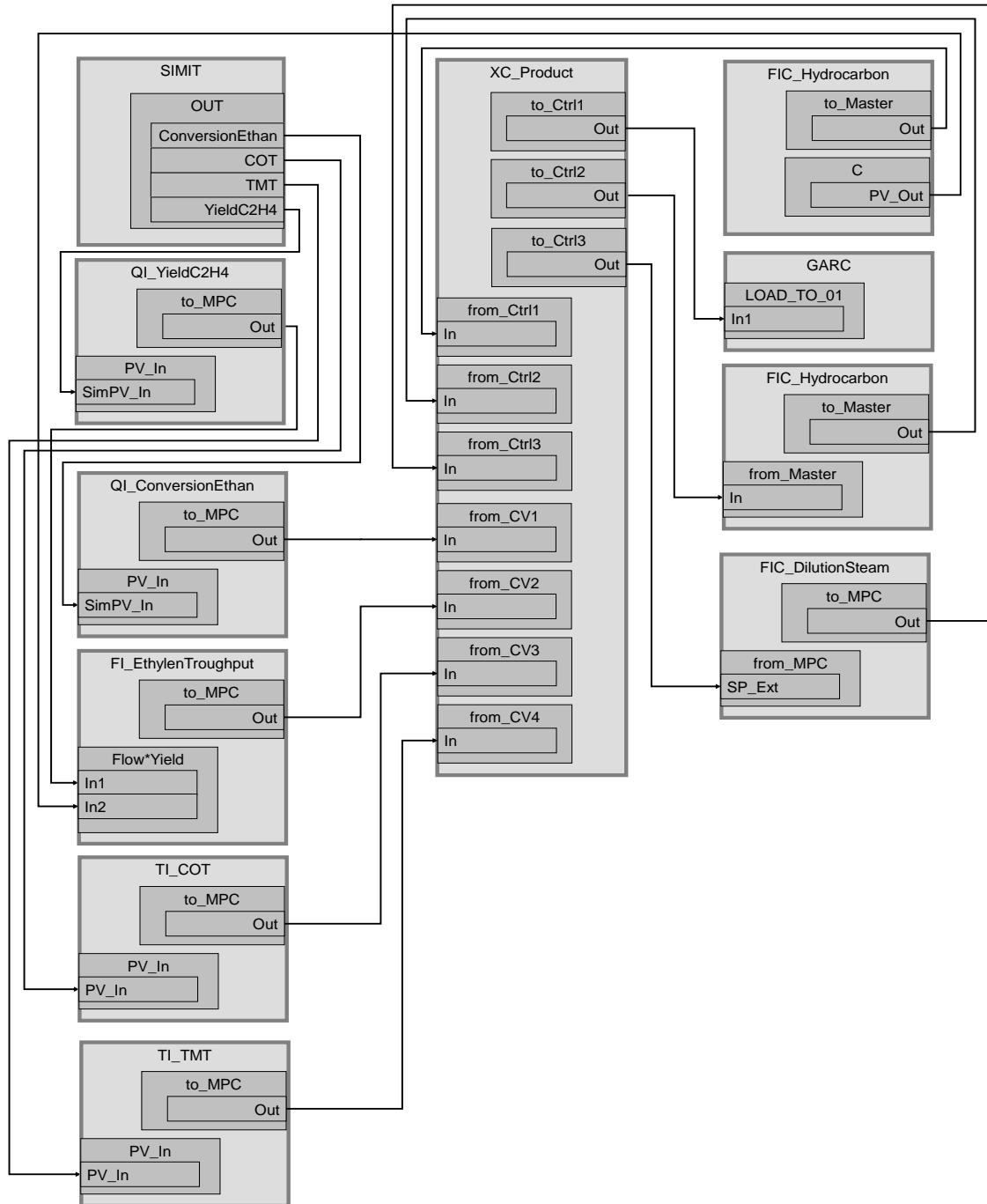
In order to achieve the above objectives, the MPC sets the target value for the GARC and thus indirectly the burner inflow in the form of fuel gas and air. In addition, the inflow of the reactant is predetermined. The ratio of water vapor to educt is influenced by the MPC as the third manipulated variable, but the permitted range for this ratio is very narrow. This leads to the fact that the manipulated variable limitation is active and thus to a limited influence of the third MPC manipulated variable. Although the MPC theoretically has three degrees of freedom, usually only two of them can be used. As only two degrees of freedom are effectively available due to the limited number of manipulated variables, additional controlled variables can no longer be precisely controlled to the setpoint. In order to nevertheless guarantee a safe plant condition, the temperatures COT ("Coil Outlet Temperature") and TMT ("Tube Metal Temperature") are kept within tolerance bands by the MPC as additional controlled variables. As soon as one of the two temperatures threatens to leave the tolerance range, they are considered by the MPC with high priority.

In total this results in a 4x3 MPC. Here, however, the third manipulated variable can only be used to a very limited extent. As long as both temperature control variables are within the permitted range, the control task is effectively reduced to a 2x2 problem that can be easily mastered by the MPC.

The following table provides an overview of the components and control module types used.

CM	CMT	Selected variants	Description
XC_Product	ModPreCon	<ul style="list-style-type: none"> <li>• IF_Ctrl_1</li> <li>• IF_Ctrl_2</li> <li>• IF_Ctrl_3</li> <li>• IF_Ctrl_4</li> </ul>	Multivariable controller as master controller
FI_EthylenThroughput	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> <li>• To_Indicate</li> </ul>	Control Module for indication of ethylene throughput
QI_ConversionEthan	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> <li>• To_Indicate</li> </ul>	Control Module for displaying the conversion rate of the ethane supplied
QI_YieldC2H4	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> <li>• To_Indicate</li> </ul>	Control Module to display the amount of ethylene produced
TI_COT	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> <li>• To_Indicate</li> </ul>	Control Module to display the output temperature of the coil (COT = Coil Outlet Temperature)
TI_TMT	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> <li>• To_Indicate</li> </ul>	Control Module for displaying the shell temperature of the tube metal (TMT = Tube Metal Temperature)

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



## 5.4.2 Parameter assignment

### XC\_Product

The following variables are used and connected for control with the multi-variable controller Control Module "XC\_Product".

CVs (Controlled Variables):

- CV1 Conversion rate of ethane
- CV2 Ethylene throughput
- CV3 Temperature at the output of the coil
- CV4 Temperature of the tube metal

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

- MV1 Burner load
- MV2 Flow rate of the educt
- MV3 Educt/water vapor ratio

The measurement loop contains communication modules for connecting slave controllers and for displaying control variables and is an instance of the "ModPreCon" measurement loop type.

Block	Connection	Value	Use
MPC	SP1	65.849	Setpoint for control variable 1
MPC	SP2	10.302	Setpoint for control variable 2
MPC	SP3	855.0	Setpoint for control variable 3
MPC	SP4	1000.0	Setpoint for control variable 4
MPC	SP1DeadB	0.0	Dead band for control variable 1
MPC	SP2DeadB	0.0	Dead band for control variable 2
MPC	SP3DeadB	20.0	Dead band for control variable 3
MPC	SP4DeadB	50.0	Dead band for control variable 4
MPC	PreFilt1	0.0	Settling time for control variable 1
MPC	PreFilt2	0.0	Settling time for control variable 2
MPC	PreFilt3	20.0	Settling time for control variable 3
MPC	PreFilt4	50.0	Settling time for control variable 4
MPC	MV1Man	375.0	Control value in manual mode
MPC	MV2Man	19.35	Control value in manual mode
MPC	MV3Man	0.315	Control value in manual mode
MPC	MV4Man	0.0	Control value in manual mode
MPC	DB_No	18	DB number with controller data
from_CV1	In		Connection of the conversion rate of the ethane supplied (QI_ConversionEthan\to_Indicate.Out)
from_CV2	In		Connection of ethylene throughput (QI_EthylenThroughput\to_Indicate.Out)
from_CV3	In		Connection of the temperature at the output of the coil (TI_COT\to_Indicate.Out)
from_CV4	In		Connection of the temperature of the tube metal (TI_TMTI\to_Indicate.Out)

Block	Connection	Value	Use
to_Ctrl1	Out		Control value for burner load (FIC_FuelGas\from_Master.In)
to_Ctrl2	Out		Control value for educt flow rate (FIC_Hydrocarbon\from_Master.In)
to_Ctrl3	Out		Control value for the educt/water vapor ratio (FIC_Catalyst\from_Master.In)
from_Ctrl1	In		Connection from the burner gas Control Module (FIC_FuelGas\to_Master.Out)
from_Ctrl2	In		Connection of the educt Control Module (FIC_Hydrocarbon\to_Master.Out)
from_Ctrl3	In		Connection of the ratio Control Module (FFIC_DilutionSteam\to_MPC.Out)

### FI\_EthylenThroughput

The display Control Module "FI\_EthylenThroughput" visualizes the ethylene throughput and is used to provide the process value for the MPC.

However, the ethylene throughput could only be measured with a long dead time in the separation section of the entire cracker plant, so the throughput is calculated as follows:

$$\text{EthylenThroughput} = \text{FeedHydrocarbon} \cdot \text{YieldC2H4}$$

The inflow from the hydrocarbon is controlled by the controller "FIC\_Hydrocarbon" and the conversion rate to ethylene is calculated by the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\ThroughputC2H4)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	50.0	Maximum value of the process value
PV_Scale	LoScale	1.0	Minimum value of the process value
PV_Unit	IN	1328	Unit of the process value (t/h)
To_Indicate	Out		Connection to the controlled variable of the multi-variable controller (XC_Product\from_CV2.In)

### QI\_ConversionEthan

The display Control Module "QI\_ConversionEthan" visualizes the conversion rate of the supplied ethane (C<sub>2</sub>H<sub>6</sub>), which is calculated by the soft sensor. The measurement loop provides the process value for the MPC.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\ConvEthan.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\I.S.Out)
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1342	Process value unit (%)
To_Indicate	Out		Connection to the controlled variable of the multi-variable controller (XC_Product\from_CV1.In)

### QI\_YieldC2H4

The display Control Module "QI\_YieldC2H4" visualizes the yield of ethylene (C<sub>2</sub>H<sub>4</sub>), which is calculated by the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\YieldC2H4.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\I.S.Out)
PV_Scale	HiScale	100.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1342	Process value unit (%)
I	PV_Out		Wiring for ethylene throughput calculation (FI_EthylenThroughputFlow*Yield.In2)

### TI\_COT

The display Control Module "TI\_COT" visualizes the temperature at the output of the coil and is used to provide the process value for the MPC.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\COT.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\I.S.Out)
PV_Scale	HiScale	800.0	Maximum value of the process value
PV_Scale	LoScale	600.0	Minimum value of the process value

Block	Connection	Value	Use
PV_Unit	PV_InUnit	1001	Process value unit (°C)
To_Indicate	Out		Connection to the controlled variable of the multi-variable controller (XC_Product\from_CV3.In)

**TI\_TMT**

The display Control Module "TI\_TMT" visualizes the jacket temperature of the pass, which is calculated by the soft sensor. The measurement loop provides the process value for the MPC.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\TMT.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	800.0	Maximum value of the process value
PV_Scale	LoScale	600.0	Minimum value of the process value
PV_Unit	PV_InUnit	1001	Process value unit (°C)
To_Indicate	Out		Connection to the controlled variable of the multi-variable controller (XC_Product\from_CV4.In)

## 5.5 Soft sensor (SoftSensor)

The yield and the conversion rate are of decisive importance for the economic efficiency of a steam cracker. However, the material and reaction properties cannot be determined directly at the outflow of the cracking furnace, but only with great delay at the downstream subsystems and often summarized for several cracking furnaces. This delay makes direct control impossible. Therefore, a soft sensor calculates the variables that are of decisive importance for process control and thus enables the direct control concept of these variable.

To calculate the ethane conversion rate and ethylene yield, the soft sensor uses a simulated dynamic process model and the current values of the input variables into the system. The internal system states to be measured are compared with the corresponding measured values of the real process and used to correct the estimated states.

For applications in real plants, the model-based soft sensor for each cracking furnace is implemented in PSE's simulation software gPROMS and coupled to SIMATIC PCS 7 via OPC UA.

Coupled differential-algebraic equations are used to realistically map the system behavior of a steam cracker. More than 50,000 equations are required for the "Steam Cracker" model, so implementation of the soft sensor in SIMATIC PCS 7 is not possible. In this Unit Template, the non-measurable variables are simulated and made available in the simulation, therefore the Equipment Module "SoftSensor" only contains the Control Modules for correcting the internal measured states of the soft sensor.

### 5.5.1 Setup

In the "SoftSensor" Equipment Module, the Control Modules are available which are measured at the system and used to correct the estimated states.

The following table provides an overview of the components and control module types used.

CM	CMT	Selected variants	Description
PI_CIP	MonAn	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale</li> </ul>	Control Module for indicating the pressure at the inlet of the tube bundle (CIP = Coil inlet Pressure)
PI_COP	MonAn	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale</li> </ul>	Control Module for indicating the pressure at the outlet of the tube bundle (COP = Coil Outlet Pressure)
QI_FG_H2	MonAn	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale</li> </ul>	Control Module for indicating the proportion of H2 (hydrogen) in the burner gas
QI_HC_C3H8	MonAn	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale</li> </ul>	Control Module for displaying the proportion of C3H8 (propane) in the feed educt
TI_Air	MonAn	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale</li> </ul>	Control Module for displaying the temperature of the air volume in the burner
TI_CIT	MonAn	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale</li> </ul>	Control Module to display the input temperature of the tube bundle (CIT = Coil Inlet Temperature)
FIC_FuelGas	MonAn	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale</li> </ul>	Control Module for display of burner gas temperature

CM	CMT	Selected variants	Description
TI_Hydrocarbon	MonAn	<ul style="list-style-type: none"> <li>PV</li> <li>PV_Scale</li> </ul>	Control Module to display the temperature of the reactant

No Control Module is provided for the temperature of the water vapor, as the water vapor is usually supplied from a central steam supply within the plant and therefore the temperature has a relatively small fluctuation range. A constant value is assumed in the simulation.

The Equipment Module "SoftSensor" has no cross-chart connections, the corresponding values for the display Control Modules are provided by the simulation.

## 5.5.2 Parameter assignment

### PI\_CIP

The display Control Module "PI\_CIP" visualizes the pressure at the input of the coil and is used to provide the process value for the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\Noise_PI_CIP.Noise)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	100.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1137	Unit of the process value (bar)

### PI\_COP

The display Control Module "PI\_COP" visualizes the pressure at the output of the coil and is used to provide the process value for the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\Noise_PI_COP.Noise)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	2.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1137	Unit of the process value (bar)

**QI\_FG\_H2**

The display Control Module "QI\_FG\_H2" visualizes the proportion of hydrogen in the burner gas and is used to provide the process value for the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\Noise_QI_FG_H2.Noise)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	100.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1342	Unit of the process value (percent)

**QI\_HC\_C3H8**

The display Control Module "QI\_HC\_C3H8" visualizes the proportion of propane (C3H8) in the educt and is used to provide the process value for the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\Noise_QI_HC_C3H8.Noise)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	100.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1342	Unit of the process value (percent)

**TI\_Air**

The display Control Module "TI\_Air" visualizes the temperature of the air volume in the burner and is used to provide the process value for the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Process\Noise_TI_Air.Noise)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	100.0	Maximum value of the process value
PV_Scale	LoScale	10.0	Minimum value of the process value
PV_Unit	PV_InUnit	1001	Process value unit (°C)

**TI\_CIT**

The display Control Module "TI\_CIT" visualizes the temperature at the input of the pass and is used to provide the process value for the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Softsensor\Noise_TI_CIT.Noise)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	800.0	Maximum value of the process value
PV_Scale	LoScale	600.0	Minimum value of the process value
PV_Unit	PV_InUnit	1001	Process value unit (°C)

**TI\_Fuelgas**

The display Control Module "TI\_Fuelgas" visualizes the temperature of the burner gas and is used to provide the process value for the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Process\Noise_TI_FuelGas.Noise)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	100.0	Maximum value of the process value
PV_Scale	LoScale	10.0	Minimum value of the process value
PV_Unit	PV_InUnit	1001	Process value unit (°C)

**TI\_Hydrocarbon**

The display Control Module "TI\_Hydrocarbon" visualizes the temperature of the reactant and is used to provide the process value for the soft sensor.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	SimPV_In		Interconnection for the simulated process value (Process\Noise_TI_Hydroca.Noise)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	100.0	Maximum value of the process value
PV_Scale	LoScale	10.0	Minimum value of the process value
PV_Unit	PV_InUnit	1001	Process value unit (°C)

## 5.6 Key Performance Indicators (KPI)

In addition to the four process characteristics, yield, conversion rate, coil outlet temperature (COT) and tube metal temperature (TMT), for the control concept of the multi-variable controller, the soft sensor calculates further material and reaction properties that are not determined directly at the outlet of the cracking furnace.

### 5.6.1 Setup

The Equipment Module "KPI" contains the visualization of further key performance indicators, which inform the operator about further material and reaction properties of the process. The properties:

- Severity P/E (Propylene/Ethylene)
- Severity M/P (Methane/Propylene)
- Coking rate

are formed by the soft sensor through the parallel simulation of a process model and visualized via additional display Control Modules.

In addition, further yield coefficients can be calculated by the soft sensor, such as the yields of

- Propylene
- Methane
- Hydrogen
- Acetylene
- C4s
- C5plus

For reasons of clarity, however, these Control Modules are not implemented.

The following table provides an overview of the components and control module types used.

CM	CMT	Selected variants	Description
PI_PressureDrop	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> </ul>	Control Module for displaying the pressure difference between the furnace inlet and outlet
QI_CokeLevel	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> </ul>	Control Module for indicating the thickness of deposits on the pipes
QI_CokingRate	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> </ul>	Control Module for display the increase in thickness of deposits
QI_SeverityMP	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> </ul>	Control Module for indicating the ratio of methane to propylene
QI_SeverityPE	MonAn	<ul style="list-style-type: none"> <li>• PV</li> <li>• PV_Scale</li> </ul>	Control Module for indicating the ratio of propylene to ethylene

## 5.6.2 Parameter assignment

### PI\_PressureDrop

The display Control Module "PI\_PressureDrop" visualizes the pressure difference between the furnace inlet and outlet.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	PV_In		Interconnection for the simulated process value (Softsensor\PressDrop.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	5.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1137	Unit of the process value (bar)

### QI\_CokeLevel

The display Control Module "QI\_CokeLevel" visualizes the thickness of deposits on the pipes calculated by the soft sensor. The deposits change the heat transfer between the outside and inside of the pipes. In case of excessive contamination, it is more economical to switch off the system and clean the pipes. The Control Module thus enables cleaning to be carried out at the best economic time.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	PV_In		Interconnection for the simulated process value (Softsensor\Initial value.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	2000.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1013	Process value unit (mm)

### QI\_CokingRate

The display Control Module "QI\_CokingRate" visualizes the increase of deposits on the pipes, this is calculated by the soft sensor. The Control Module makes it possible to plan the times for cleaning at an early stage.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	PV_In		Interconnection for the simulated process value (Softsensor\CokingRate.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7\S.Out)
PV_Scale	HiScale	20.0	Maximum value of the process value

Block	Connection	Value	Use
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	1	Process value unit (mm/month)

**Note**

The Unit Template uses customer-specific units that deviate from the IEC 611582 standard. These units are defined in the "APLCustomerUnits.xml" and are located in the project path in the folder "GraCS". Further information on the customer-specific units can be found in the function manual "SIMATIC Process Control System PCS 7 Advanced Process Library (V9.0 SP2)". The function manual can be found under <https://support.industry.siemens.com/cs/ww/en/view/109760968>

**QI\_SeverityMP**

The display Control Module "QI\_SeverityMP" visualizes the concentration of methane in propylene. The severity can only be estimated by a soft sensor at runtime.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	PV_In		Interconnection for the simulated process value (Softsensor\SeverityMP.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7S.Out)
PV_Scale	HiScale	10.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	3	Process value unit (%/%)

**QI\_SeverityPE**

The display Control Module "QI\_SeverityMP" visualizes the concentration of propylene to ethylene. The severity can only be estimated by a soft sensor at runtime.

The following table shows the project engineering of the instance from "MonAn".

Block	Connection	Value	Use
PV	PV_In		Interconnection for the simulated process value (Softsensor\SeverityPE.Out)
PV	SimOn		Switching between SIMIT and PLCSIM (SIMIT_PCS7S.Out)
PV_Scale	HiScale	10.0	Maximum value of the process value
PV_Scale	LoScale	0.0	Minimum value of the process value
PV_Unit	PV_InUnit	3	Process value unit (%/%)

## 5.7 Sequential Functional Chart (SFC)

Sequential Functional Charts support the plant operator in starting up and shutting down a facility, and in the event of faults, and can be adapted to specific circumstances.

The "Steam Cracker" is designed for continuous operation, where individual parameters (educt inflow or educt to steam ratio) can change slightly during the running process. The steam cracker contains the SFC "StartUp" to start up the Unit Template and simulation, which leads the individual components of the steam cracker into the respective operating points.

When the steam cracker is started, a controller or actuator changes to automatic mode with external setpoint in each step. In the transition that follows, the "Automatic" operating mode and control deviation are checked. Finally, the setpoints for the controlled variables of the multi-variable controller are specified.

This SFC is only to be understood as a reference point with regard to real steam crackers and was created to match the simulation requirements. For use in real systems, start-up controlling must be created according to the process-related requirements. For example, it must be clarified whether the steam cracker is first filled with educt and then steam is added, or vice versa.

### Note

To determine the setpoint and operation selection, the necessary parameterization including the schematic diagrams from the function manual "SIMATIC Process Control System PCS 7 Advanced Process Library (V9.0 SP2)" was used. The function manual can be found under <https://support.industry.siemens.com/cs/ww/en/view/109760968>.

## 6 Process simulation

To demonstrate the Unit Template the simulation is realized with PLCSIM and SIMIT. During simulation with PLCSIM, the application program is loaded into a virtual AS, whereby the process is simulated in a CFC chart. With SIMIT, the signals, devices and the process are simulated outside of PCS 7. Both simulations are independent of each other and thus allow you to select the type of simulation, depending on the available license. The task of process simulation is to understand or demonstrate the functionality of the steam cracker, especially with regard to the control functions of the multi-variable controller. There is no claim to exactly reproduce the real physical behavior of a particular cracker.

The gas phase reaction in the coils should be simulated as a system with spatially distributed parameters though this is not the case for this template. The thermal behavior of the entire furnace with the heat capacities of the steel masses is not considered, therefore the current cracker model has no delay time constants greater than 10 s. This is realistic for the gas phase reaction, but not for the temperature control systems.

All measurable values are simulated in SIMIT (respectively in PCS 7 when SIMIT is not used). In the template no external soft-sensor is coupled but the calculations are simulated in PCS 7 in a simplified way.

## 6.1 Simulation with SIMIT

SIMIT offers a simple possibility for the simulation of signals, devices and process states. The simulation contains several prefabricated, standardized and fully interconnected device and process simulations and consists of three levels:

- Signal level
- Device level
- Process level

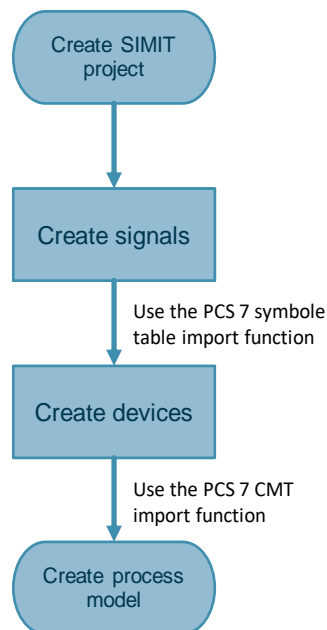
In the signal level, system signals are defined and scaled with the help of the symbol table (export from PCS 7).

In the device level, devices such as valves and motors are defined and connected to the respective signals of the signal level via connectors.

At the process level, physical processes such as material flows are modeled on the basis of states (e.g. valve position) and other parameters (e.g. maximum flow rate).

### Procedure

The following representation describes the procedure of how to create a simulation model with SIMIT.



### Note

You can find a detailed description of how to create a simulation model in SIMIT in the application example "Simulation with SIMIT and SIMATIC PCS 7 using a practical example" under the following link:

<https://support.industry.siemens.com/cs/ww/en/view/77362399>

### 6.1.1 Signals

In SIMIT, all signals required for communication are created in so-called couplings. In project, the couplings with PLCSIM have already been created and configured.

The process values are transmitted as raw data values. In SIMIT, the standardization takes place in the simulation plans. In PCS 7, these raw data are converted into process values in the driver blocks.

The screenshot shows the SIMIT software interface for the AS01 (Virtual Controller). The main window displays a table of I/O signals with columns for Symbol name, Address, Data type, System, Device, Modul, Comment, and Scaling. Below this, a Properties table for AS01 is visible, listing attributes like Time slice, Mnemonic, Simatic project name, Simatic station name, and Simatic project path.

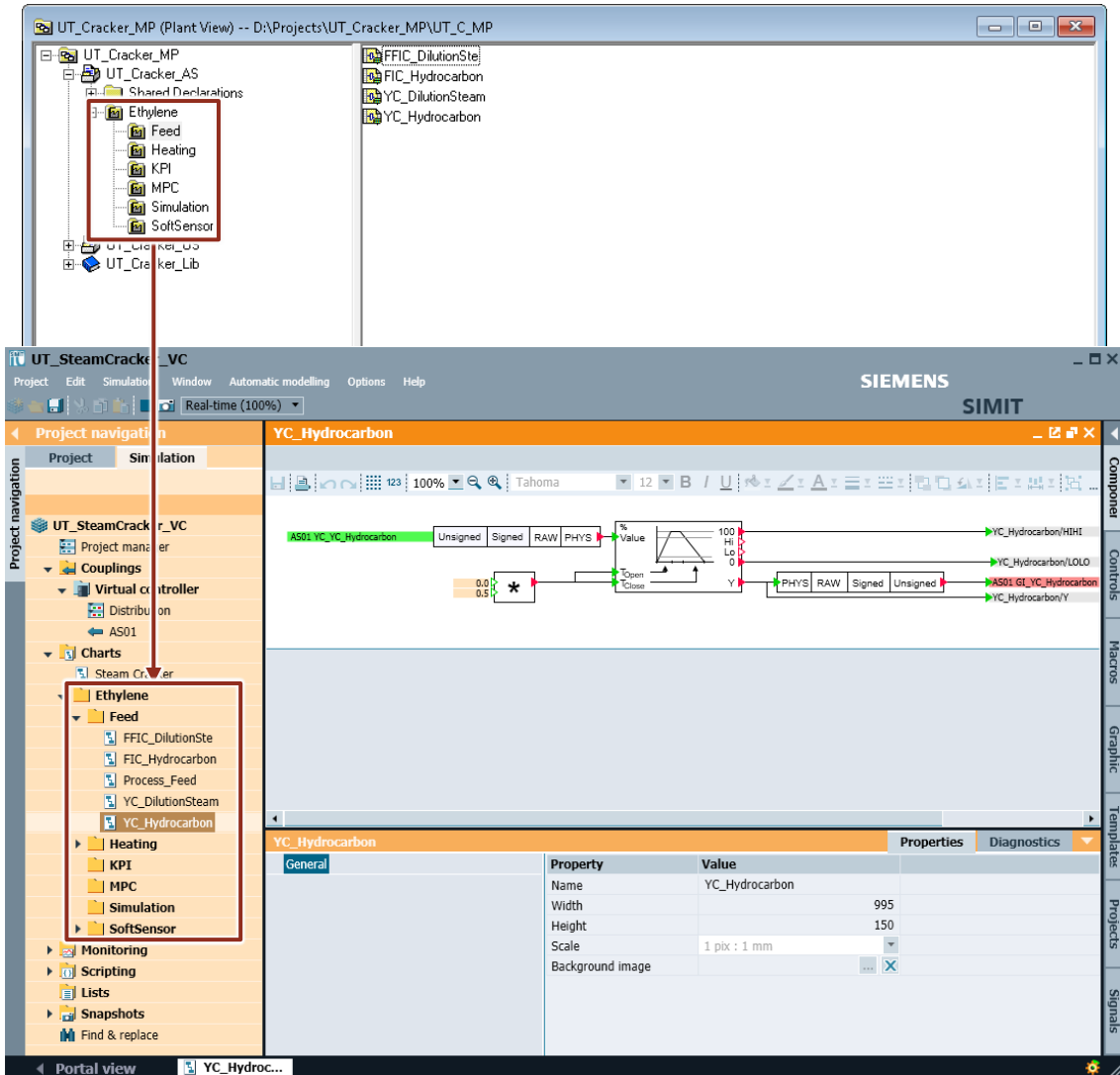
Symbol name	Address	Data type	System	Device	Modul	Comment	Scaling
51562 GI_YC_DilutionSteam	IW512	WORD	1	3	4	Feedback Signal of the YC_Diluto...	No scaling
51473 FFIC_DilutionSteam	IW514	WORD	1	3	4	Inflow of dilution steam	No scaling
59297 GI_YC_Hydrocarbon	IW516	WORD	1	3	4	Feedback Signal of the YC_Hydro...	No scaling
58608 FIC_Hydrocarbon	IW518	WORD	1	3	4	Inflow of hydrocarbon	No scaling
65193 GI_YC_Air	IW520	WORD	1	3	4	Feedback Signal of the YC_Air	No scaling
65166 FIC_Air	IW522	WORD	1	3	4	Inflow of air	No scaling
7114 GI_YC_FuelGas	IW524	WORD	1	3	4	Feedback Signal of the YC_FuelGas	No scaling

Property	Value
Time slice	2
Mnemonic	I/Q
Simatic project name	UT_Cracker_AS
Simatic station name	AS01
Simatic project path	D:\Projects\UT_Cracker_MP\UT_C_...

### 6.1.2 Device simulation

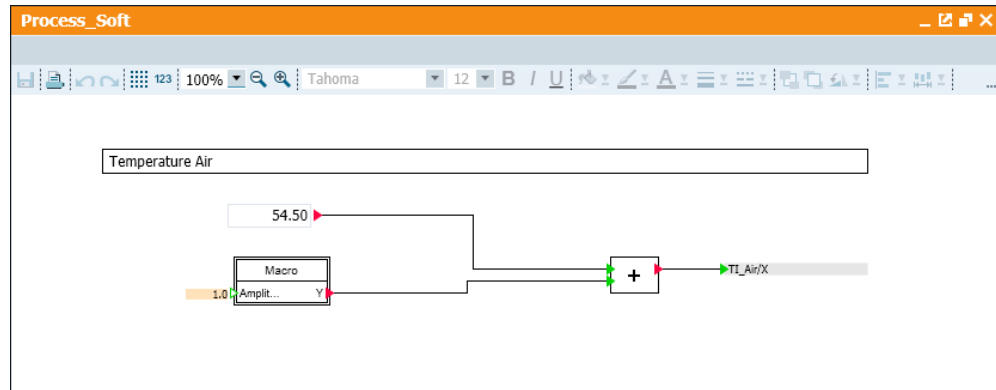
The structure of the SIMIT project is derived from the plant hierarchy of the PCS 7 project. The plans for simulating the corresponding actuators and sensors are configured in the individual folders. In addition, each relevant folder contains a chart for simulating the process values.



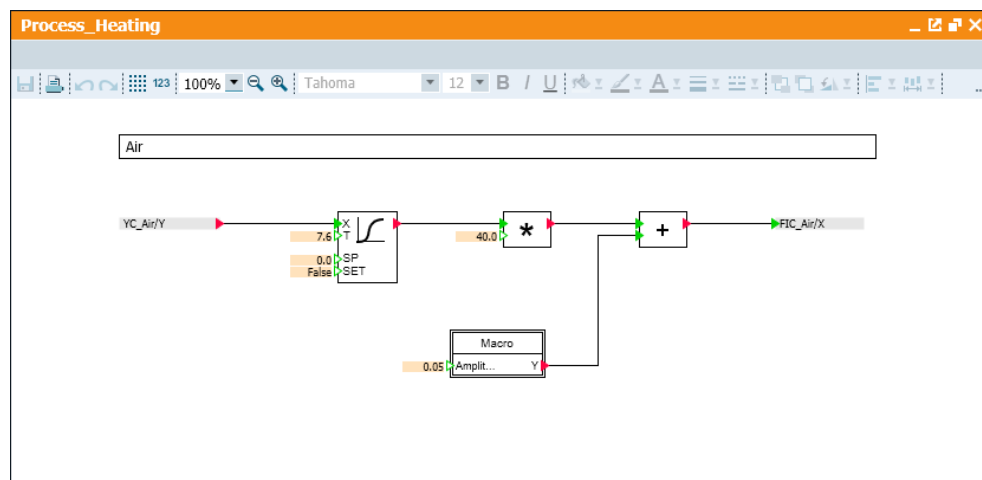
### 6.1.3 Process simulation

For the simulation of the process values, an additional chart ("Process\_xxx") is implemented in each relevant folder. The simulation of the process values is reduced to a minimum for reasons of complexity.

In some cases, static values were used, to which only a measurement noise was added. The static values can be adjusted in SIMIT using an input field.



For controlled processes, the valve position is used with a factor plus measurement noise as the process value to be controlled.

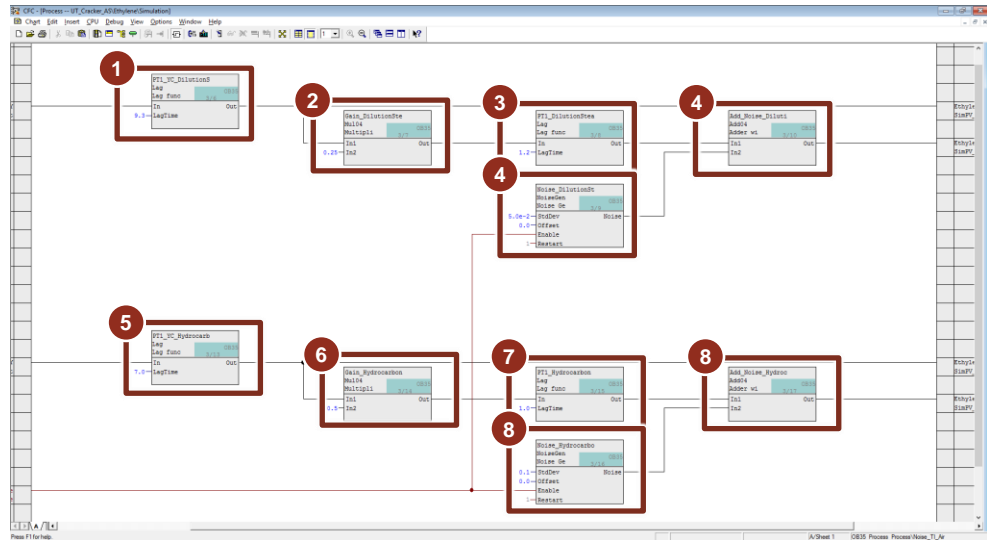




## 6.2 Simulation with PLCSIM

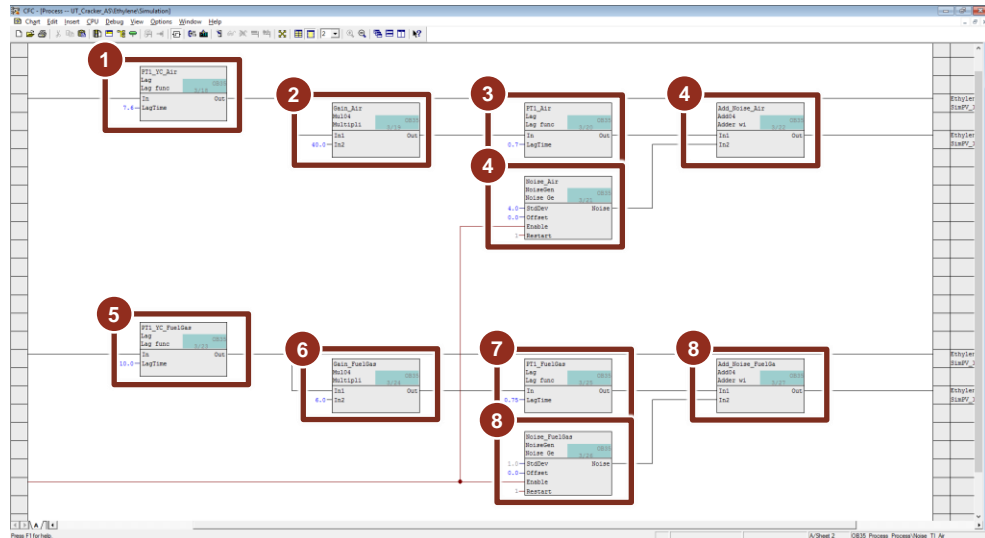
During simulation with PLCSIM, the required feedback and processes are simulated in the CFC. For valve feedback, the manipulated variable is delayed via PT1 element and transmitted to the valve module as a position feedback signal. From the simulated feedback of the valve, the respective flow rate is simulated by a first-order linear transfer function and made available for control.

### 6.2.1 Simulation for the Equipment Module "Feed"



1. Delay of the control of the valve for the supply of water vapor (PT1 behavior with 9.3 s delay)
2. Conversion of the valve opening into a flow of air (100 % valve opening corresponds to an inlet of 25 t/h)
3. Flow delay (PT1 behavior with 1.2 s delay)
4. Creation of measurement noise
5. Delay in actuating the valve for the feed of the reactant (PT1 behavior with 7.0 s delay)
6. Conversion of the valve opening into a flow of the reactant (100 % valve opening corresponds to an inlet of 50 t/h)
7. Flow delay (PT1 behavior with 1.0 s delay)
8. Generation of measurement noise

## 6.2.2 Simulation for the "Heating" Equipment Module



1. Delay in controlling the valve for the supply of air (PT1 behavior with 7.6 s delay)
2. Conversion of the valve opening into a flow of air (100 % valve opening corresponds to an inlet of 4000 kmol/h)
3. Flow delay (PT1 behavior with 0.7 s delay)
4. Creation of measurement noise
5. Delay of the control of the valve for the supply of fuel gas (PT1 behavior with 10.0 s delay)
6. Conversion of the valve opening into a flow of fuel gas (100 % valve opening corresponds to an inlet of 600 kmol/h)
7. Flow delay (PT1 behavior with 0.75 s delay)
8. Generation of measurement noise

## 6.3 Soft sensor

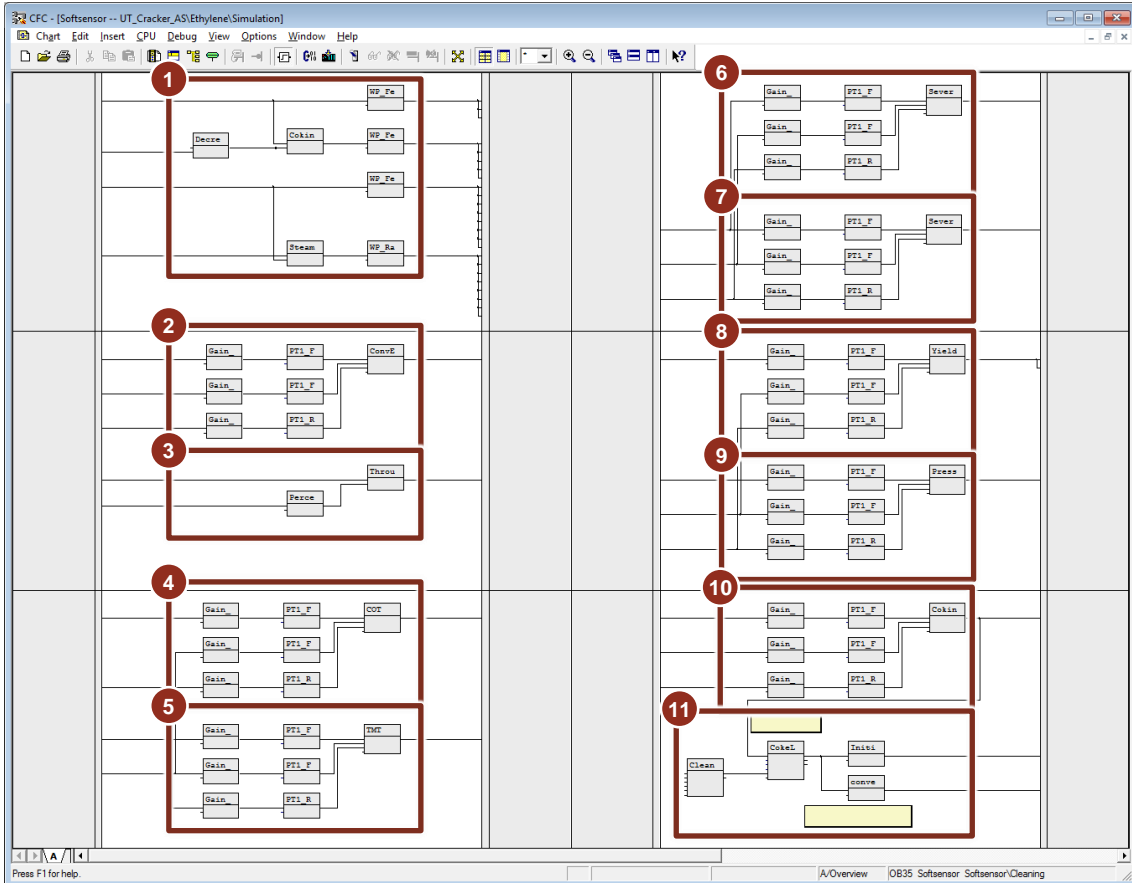
The process variables "EthyleneThroughput" (throughput of ethylene), "ConversionEthan" (conversion rate of the ethane supplied), "COT" (temperature of the material mixture at the coil outlet) and "TMT" (jacket temperature of the tube bundle) are necessary for multi-variable control. In a real system, only the initial temperature of the tube bundle can be measured. All other process variables are estimated by the soft sensor. This soft sensor is not part of the Unit Template and therefore the values estimated by the soft sensor are also calculated in the simulation and provided for the display Control Modules.

For the simulation of the soft sensor, a matrix of linear dynamic transfer functions is used as a model. The process model is a 4x9 multi-variable system in which the influence of each input variable on each output variable is simulated by a separate partial transfer function. The model describes the temporal behavior of process deviations from the operating point. The process simulation for coking the pipes runs in fast motion, i.e. the period of one month in real time is simulated in approximately six minutes.

The operating points, amplifications and delay times can be parameterized for each process variable. The partial transfer functions are implemented with PT1 behavior. Each partial transfer function receives the respective difference between the

predefined operating point and the current value of the input variables and calculates the output corresponding to its transfer functions. At the end, the associated operating point is added for each process output variable. Furthermore, noise can be added to the output signal.

The following figure shows the realization of the soft sensor with the corresponding partial transfer functions.

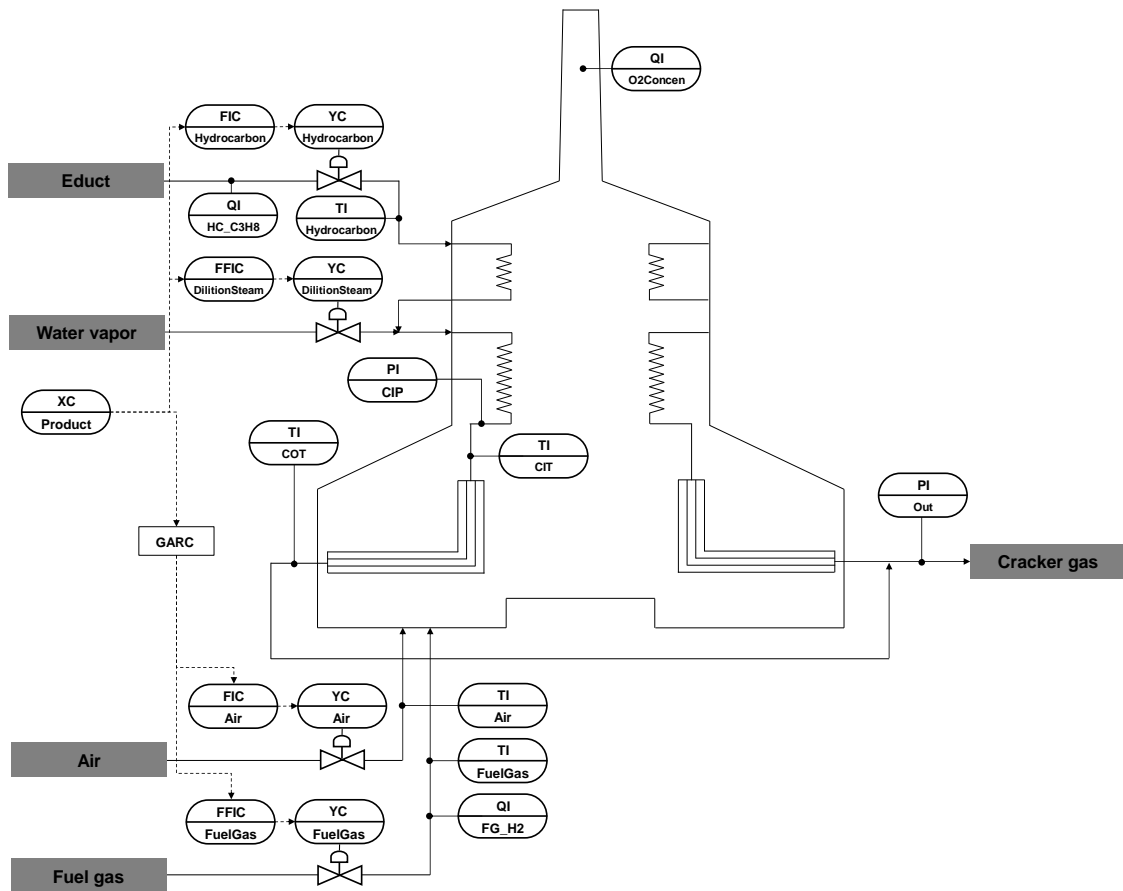


1. Calculating the operating points
2. Conversion rate of ethane
3. Ethylene throughput
4. Temperature at the output of the coil
5. Temperature of the tube metal
6. Concentration of methane to propylene
7. Concentration of propylene to ethylene
8. Amount of produced ethylene
9. Pressure difference between the furnace inlet and the furnace outlet
10. Increase in deposits on the pipes
11. Thickness of deposits on the pipes

# 7 Useful information

## 7.1 P&I diagram

The following figure shows the individual components of the steam cracker in the piping and instrumentation diagram.

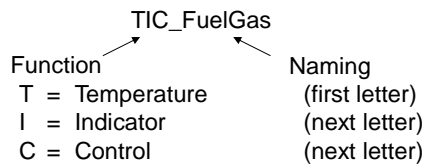


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## 7.2 Project structure

### 7.2.1 CFC chart naming convention

A uniform naming convention was used to designate the Control Modules. The function is named according to the EN 62424 European Standard. The following figure shows how a Control Module designation is put together:



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

First letter	Meaning
F	Flow
L	Level
M	Moisture
N	Motor
P	Pressure
Q	Quality, Concentration
S	Speed (velocity, rotational speed, frequency)
T	Temperature
W	Weight
X	Freely selectable first letter
Y	Control valve

Next letter	Meaning
C	Control
F	Fraction
I	Indication
S	Binary control function or switching function (not not safety-relevant) ("Switching")
T	Transmitter (analog value processing)
H	High
L	Low

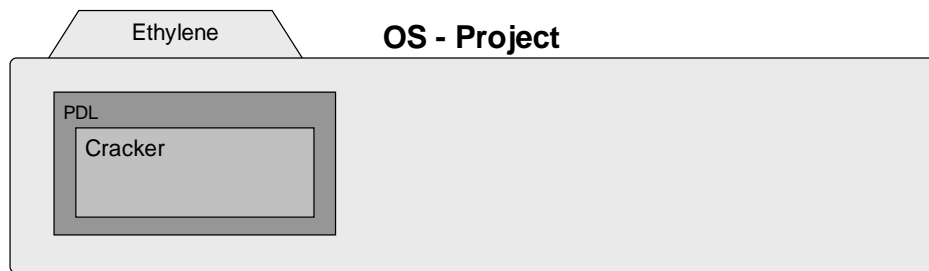
### 7.2.2 Plant view

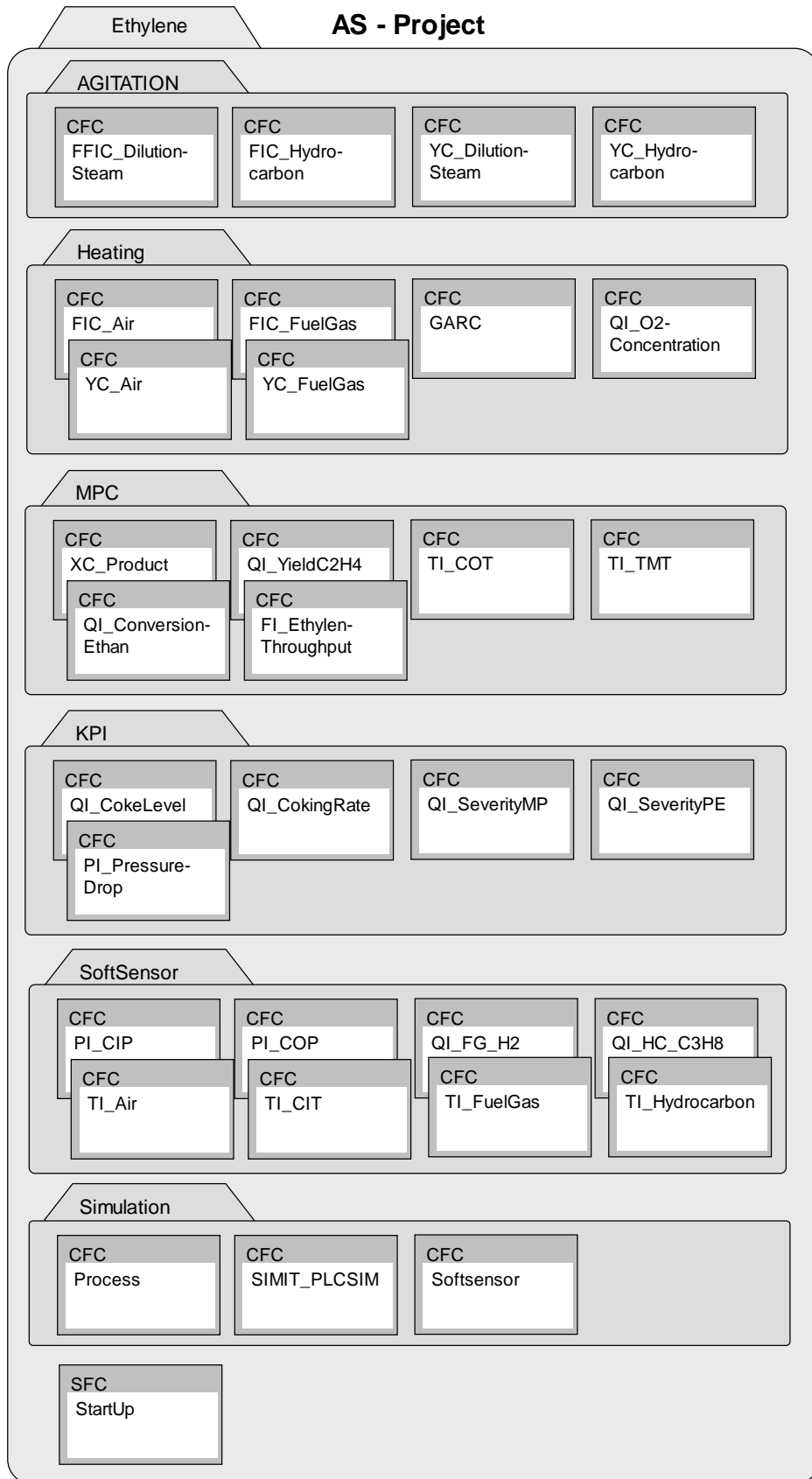
The "Steam Cracker" Unit Template is implemented in two hierarchy levels from a plant view.

In the AS project the first hierarchy level is empty and in the subordinate hierarchy level there is a hierarchy folder with the necessary CFCs for each Equipment Module (functional unit) of the steam cracker. The simulation of the steam cracker is realized with PLCSIM and SIMIT and can be removed for use on a real plant.

The first hierarchy level of the OS project contains the detailed process picture "Cracker.pdl" of the steam cracker.

The structure of the multi-project is shown in the following two figures.





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## 7.3 Additional information

### 7.3.1 Additional disturbance variables

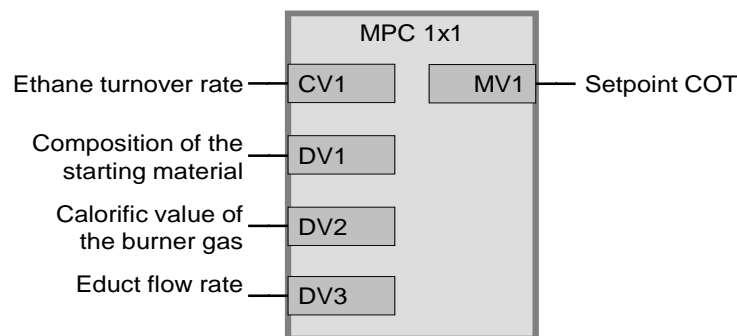
In the control concept, additional measurable disturbance variables can be considered in order to increase the robustness of the process against changing process conditions. Reasonable disturbance variables are, for example, the composition of the educts or the calorific value of the fuel gas.

The Control Modules "QI\_FG\_H2" and "QI\_HC\_C3H8" visualize the proportion of propane (C3H8) in the educt and the proportion of hydrogen (H2) in the burner gas and are indicators for a changed educt composition or other calorific value. If these process variables are available in a real plant, they can be used for MPC feedforward control.

### 7.3.2 Control concept with a 1x1 MPC

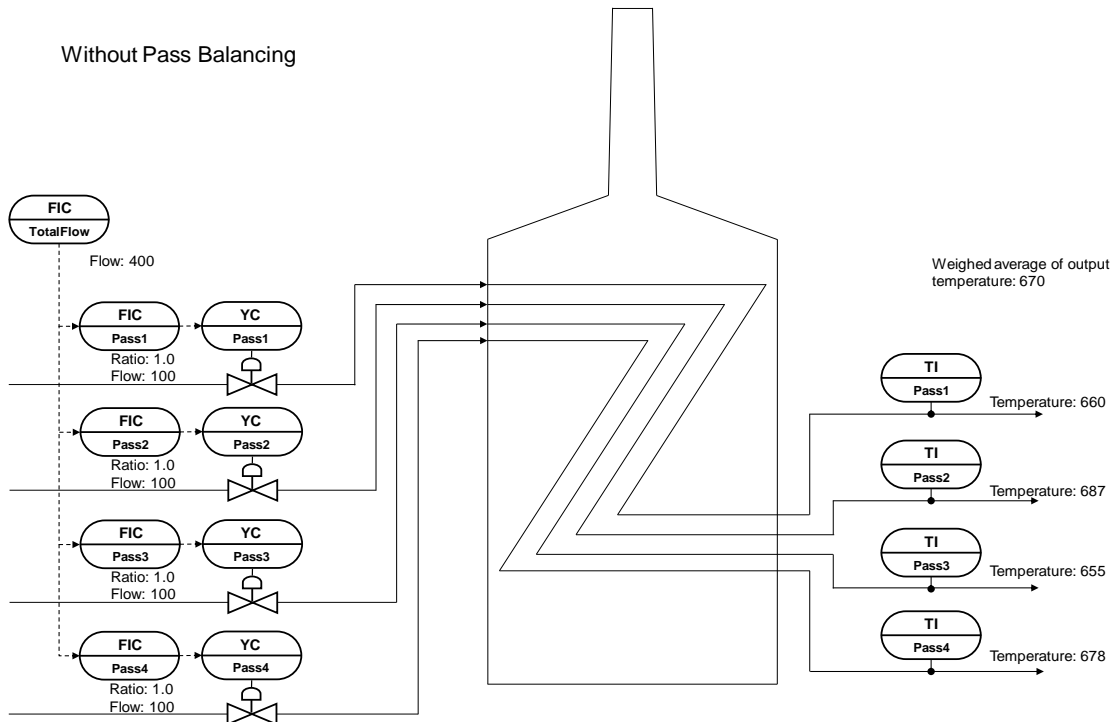
As an alternative to the presented 4x3 control concept of the MPC, the control of the steam cracker can be performed with a 1x1 MPC and additional feedforward control. The 1x1 control concept enables the plant operator to adjust the amount of educt as well as the ratio between educt and water vapor. Instead of the control value for the burner load, the setpoint output temperature of the tube bundle (COT = Coil Outlet Temperature) of a subordinate temperature controller can also be used.

Due to the reduced number of degrees of freedom, only one controlled variable can be regulated; in this example, the ethane conversion rate is regulated.

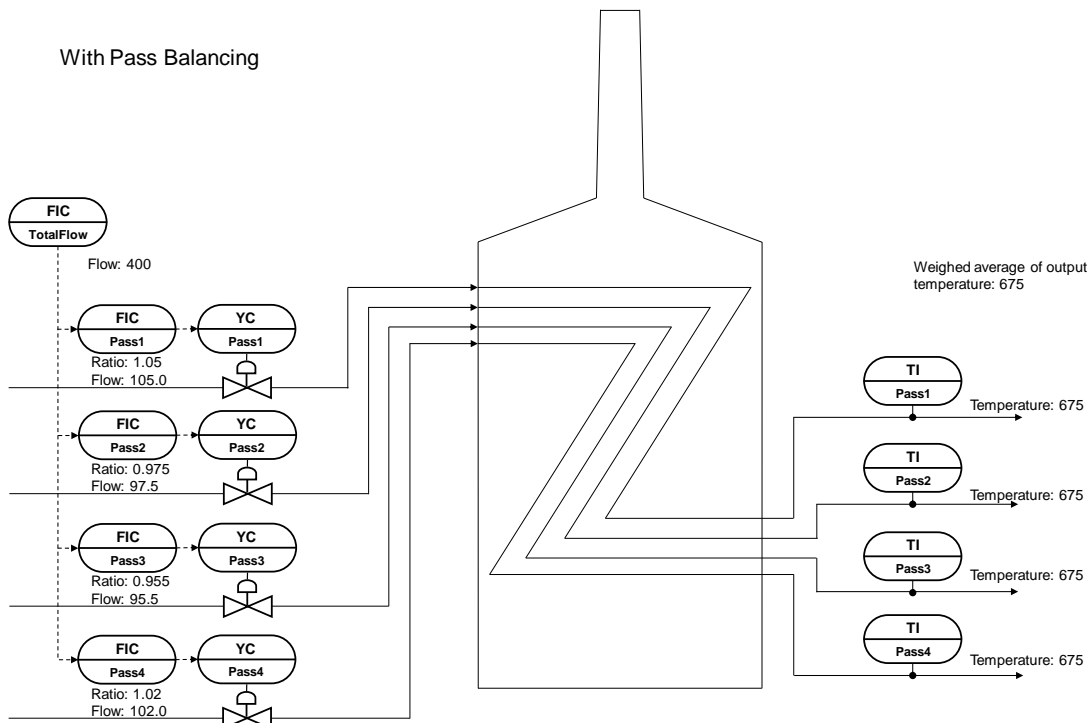


### 7.3.3 Pass Balancing

The aim of the so-called "Pass Balancing" is, to keep for all passes (coils), which are heated by a burner cell, the same COT despite varying degrees of coking. The requirement for this is that each coil has its own flow controller with control valve. The total flow rate of the reactant is the sum of all coils and is controlled in the main supply line by a separate flow controller.



Pass Balancing calculates a weighted COT average of all coils, using the respective flow rate as the weighting factor. The deviation of the individual COT values from this mean value are the setpoints for the controllers. The output temperatures of the tube bundle are controlled by the flow ratio factors for the individual coils.

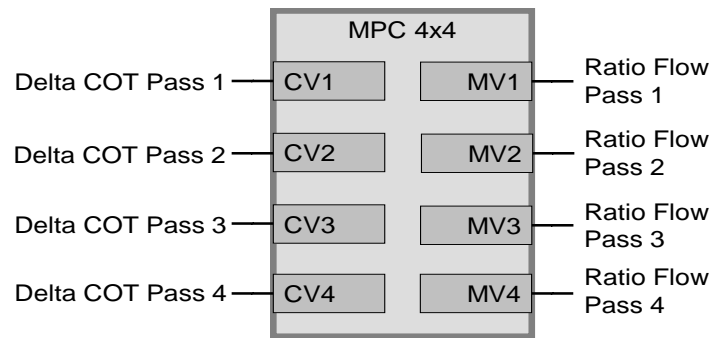


The "Pass Balancing" concept can be combined with the previous superimposed MPC concept for the total cracker, if the average COT is influenced by the total product flow as before. An additional controlled variable and manipulated variable

## 7 Useful information

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is required for each passport. In principle, the Pass Balancing can be solved with SISO controllers, an MPC is also possible as shown in the following figure as an example for 4 passes.



## 8 Appendix

### 8.1 Service and support

#### Industry Online Support

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[support.industry.siemens.com/cs/ww/en/sc/2067](http://support.industry.siemens.com/cs/ww/en/sc/2067)

## 8.2 Links and literature

No.	Topic
\1\	Siemens Industry Online Support <a href="https://support.industry.siemens.com">https://support.industry.siemens.com</a>
\2\	Link to this entry page of this application example <a href="https://support.industry.siemens.com/cs/ww/en/view/109769355">https://support.industry.siemens.com/cs/ww/en/view/109769355</a>
\3\	SIMATIC PCS 7 Overview (link collection to FAQ, manuals, compendium, forum, application examples and multimedia) <a href="https://support.industry.siemens.com/cs/ww/en/view/63481413">https://support.industry.siemens.com/cs/ww/en/view/63481413</a>
\4\	Equipment Modules for SIMATIC PCS 7 using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/53843373">https://support.industry.siemens.com/cs/ww/en/view/53843373</a>
\5\	PCS 7 Unit Template "Stirred Tank Reactor" using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/60546560">https://support.industry.siemens.com/cs/ww/en/view/60546560</a>
\6\	PCS 7 Unit Template "Fermenter" using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/68098270">https://support.industry.siemens.com/cs/ww/en/view/68098270</a>
\7\	PCS 7 Unit Template "Distillation Column" using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/48418663">https://support.industry.siemens.com/cs/ww/en/view/48418663</a>
\8\	PCS 7 Unit Template "Stirred tank reactor with Kalman filter" using the example of the Chemical Industry <a href="https://support.industry.siemens.com/cs/ww/en/view/109756215">https://support.industry.siemens.com/cs/ww/en/view/109756215</a>
\9\	PCS 7 Unit Template – Gas Fired Steam Boiler <a href="https://support.industry.siemens.com/cs/ww/en/view/109755201">https://support.industry.siemens.com/cs/ww/en/view/109755201</a>
\10\	Simulation with SIMIT and SIMATIC PCS 7 using a practical example <a href="https://support.industry.siemens.com/cs/ww/en/view/77362399">https://support.industry.siemens.com/cs/ww/en/view/77362399</a>
\11\	Simulation of a PCS 7 stirred tank reactor with SIMIT Simulation Framework <a href="https://support.industry.siemens.com/cs/ww/en/view/93148023">https://support.industry.siemens.com/cs/ww/en/view/93148023</a>
\12\	Evolution of a Digital Twin using the example of an ethylene plant <a href="http://ojs.di-verlag.de/index.php/atp_edition/article/view/2427">http://ojs.di-verlag.de/index.php/atp_edition/article/view/2427</a>
\13\	Control and optimization of steam cracker units. Pfeiffer, B.-M.; Leingang, C; Pohmer, F.; Labisch, D; Grieb, H.; Lorenz O.: Model-based monitoring Proceedings AUTOMATION 2019, Baden-Baden, 02.07.2019

## 8.3 Change documentation

Version	Date	Modifications
V1.0	10/2019	First version