PA University Curriculums
Contents

MODULE 1

• P01-01 Process description
• P01-02 Hardware configuration
• P01-03 Plant hierarchy
• P01-04 Individual drive functions
• P01-05 Functional safety
• P01-06 Control loop and other control functions
• P01-07 Importing plant design data
• P01-08 Sequential function charts

MODULE 2

• P02-01 HMI generation
• P02-02 Alarm engineering
• P02-03 Archiving
Objectives

- Categorization of process cells
- P&ID of the laboratory process cell
- Locks and recipes for the laboratory process cell
Classification of process control systems

- Classification by the number of basically different products
  - Single product process cell
  - Multi product process cell

- Classification according to the physical structure of the process cell
  - Single-line process cell
  - Multi-line process cell
  - Multi-line & multi-path process cell

- Laboratory process cell as learning example
  - Multi product, multi-line & multi-path process cell
  - Hierarchical breakdown into 4 units
PA University Curriculums
Module 1 P01-01 Process description

P&ID of the laboratory process cell

- Educt tanks
- Reaction
- Product tanks
- Rinsing
Locks and recipes

- Safe operation of the process cell needs monitoring of interactions with the process
- Requirements for the laboratory process cell:
  - Activation of actuators only when the main power switch is on and EMERGENCY OFF is unlocked
  - Protection of the tanks against overflow
  - Prevent the intake of air at the pumps
  - Pumps must not work against closed valves
  - …
- Manufacturing of a product needs a recipe
- Recipe of the laboratory process cell:
  - 350 ml of educt 3 to reactor 1 and 200 ml of educt 1 to reactor 2
  - Heating of reactor 1 up to 25 °C and 150 ml of educt 2 to reactor 2
  - …
PA University Curriculums
Module 1 P01-02 Hardware configuration

Objectives

• Theory
  • Distributed structures
  • Connection to the process
  • Operating principle of a programmable logic controller (PLC)

• Step-by-step instruction
  • Creating new projects
  • Configuring the hardware
  • Configuring the communication network
Distributed structures of process control systems

- Special structures lead to scalable process control systems
- Structures are component based and can be easily expanded
- Typical structure:
  - Process control level
  - Control level
  - Field level
Connection to the process

- Two typical ways to connect sensors and actuators to the process control system
  - Directly by bus system (intelligent devices)
  - To signal modules over standard electrical signal

- Signal modules for
  - Binary signals: DI/DO modules (DI .. digital input, DO .. digital output)
    - 1 bit of memory required per signal
  - Analog signals: AI/AO modules (AI .. analog input, AO .. analog output)
    - 16 bits of memory required per signal
    - Resolution can still be less, for example, 12 bits
Operating principle of the PLC

- Component on control level typically is a PLC
- Input and output signals are read and written cyclically and buffered in the process image
- Consistency of signals during program processing by accessing process image

Legend:
- Access to hardware
- Access to process image
- Processing sequence

Outputs

Initialization

Read the inputs

Processing of operations of program blocks
Typical processing times:
1µs Bit operations
2µs Word operations
12µs Timer/counter operation
3µs Fixed-point addition
50µs Floating-point addition

Outputs

Writing the outputs

Inputs

Process image inputs

Process image outputs
PA University Curriculums
Module 1 P01-02 Hardware configuration

Hardware configuration of the laboratory plant

- AS
- PS
- CPU (with PROFIBUS)
  - ET200M (with PROFIBUS)
    - 7x DI
    - 3x DO
    - 1x AI
    - 1x AO
    - CP (with Ethernet)
- ES/OS
  - PC (with Ethernet)

PC station as ES and OS with PCS7 software and WinCC for visualization

Ethernet connection

S7 station as AS
(here: CPU414-3DP)

PROFIBUS DP

ET 200M for I/O coupling
Objectives

- Theory
  - Structuring the laboratory process cell
  - Deriving the visualization
  - Plant View and structure of visualization

- Step-by-step instruction
  - Opening plant view
  - Creating plant hierarchy
  - Basic settings of the plant hierarchy
Structuring the laboratory process cell

- Structuring using the functional aspect
- Hierarchical breakdown into units
  - Unit 1: educt tanks
  - Unit 2: reaction
  - Unit 3: product tanks
  - Unit 4: rinsing

- Design of a labeling system according to ISA-88
  - Process cell: A1
  - Unit: T1 .. T4
    - Equipment module: B001, ..., B003, R001, ...
    - Control module: pump, valve, level, agitator, ...
Deriving the visualization

- Deriving the visualization in the operator system (OS) through the following steps:
  - Structuring the laboratory process cell
  - Creating the plant hierarchy
  - Selection of a hierarchy level as OS area
  - Running the generating process (see P02-01 HMI generation)

- All hierarchy levels below the level defined as OS area can be displayed automatically
  - Area labeling
  - Navigation hierarchy
  - Operating icons for implemented function blocks
  - Group alarms
Plant hierarchy and the effect on visualization

OS area

Operating screens

Plant hierarchy

A1_multipurpose_plant

T1_educt_tanks

T2_reaction

T3_product_tanks

T4_rinsing

Educt tank B001

Educt tank B002

Educt tank B003

Reactor R001

Reactor R002

Product tank B001

Product tank B002

Rinsing tank B001
Objectives

- Theory
  - Terminology of individual drive functions (IDF)
  - Individual drive functions in PCS 7
  - Individual drive function Motor

- Step-by-step instruction
  - Creating symbol tables
  - Creating CFC for IDF Motor
  - Testing the IDF
• Hierarchical structuring of the plant according to DIN EN 61512
  • Level 0: Control module
• Control module is a frequently used component
  • Project wide
  • For more than one project
• Reusing possible
  • Advantages:
    • Parameterization instead of programming
    • Tested functionality
    • Consistent handling and visualization
• Classification of control modules
  • e. g. motor, valve, …
Individual drive functions in PCS 7

• Function blocks as object-oriented model of an equipment module
  • e. g. motors and valves

• Functions:
  • Control and control mode
  • Protection and monitoring functions
  • Operator control and visualization functions
  • Messaging and alarm functions

• Function blocks as object-oriented model of a (measuring) signal
  • e.g. digital output, digital input, analog output, analog input

• Functions:
  • Scaling the digital value to the physical value range
  • Monitoring the signal quality
Individual drive function Motor_Lean (PCS 7 Advanced Process Library)

- Function block MotL
- Used for controlling pumps and stirrers in the laboratory process cell
- Properties:
  - Control with one control signal (on/off)
  - Monitoring function through running feedback
- Advantages:
  - No programming of the control, protection and monitoring functions
  - Uniform parameters
  - Uniform visualization (see P02-01 HMI generation)
Implementation of a pump of the laboratory process cell

- Pump SCE.A1.T2-P001 to empty the reactor
- Pump is driven by a motor
- The motor has the following signals
  - One signal for control
  - One signal for running feedback
- Template from PCS 7 AP library
  - MotorLean

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Address</th>
<th>Data type</th>
<th>Symbol comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1.T2.A1T2S003.SO+.O+</td>
<td>I 1.3</td>
<td>BOOL</td>
<td>pump outlet reactor R001 feedback running on</td>
</tr>
<tr>
<td>A1.T2.A1T2S003.SV.C</td>
<td>O 3.4</td>
<td>BOOL</td>
<td>pump outlet reactor R001 actuating signal</td>
</tr>
</tbody>
</table>
PA University Curriculums
Module 1 P01-05 Functional safety

Objectives

• Theory
  • Plant protection by the means of process control engineering (PCE)
  • Standardized circuit for plant protection
  • Design of a lock for the laboratory process cell

• Step-by-step instruction
  • Creating CFC for manual operation of the motor
  • Complete lock for motor in CFC
  • Interconnections between CFCs
Functional safety by means of process control engineering

- Protection of process cell against failure states
- In reference to the process variables, there are 3 value ranges

![Graph showing functional safety with curves and protection limits](image)
### Design of a lock for the pump of the laboratory process cell

- The pump may only be turned on when the main switch of the process cell is switched on and the emergency stop switch is unlocked.
- The pump must not take in air, which means the level of the reactor has to be at least 50 ml.
- The pump must not work against closed valves, which means at least one valve has to be open.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Address</th>
<th>Data type</th>
<th>Symbol comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1.A1H001.HS+-START</td>
<td>I 0.0</td>
<td>BOOL</td>
<td>Switch on main power switch</td>
</tr>
<tr>
<td>A1.A1H002.HS+-OFF</td>
<td>I 0.1</td>
<td>BOOL</td>
<td>Activate EMERGENCY OFF</td>
</tr>
<tr>
<td>A1.T2.A1T2L001.LISA+.M</td>
<td>IW 72</td>
<td>WORD</td>
<td>Actual value level reactor R001</td>
</tr>
<tr>
<td>A1.T2.A1T2X007.GO+-O+</td>
<td>I 66.3</td>
<td>BOOL</td>
<td>Open/Closed valve … feedback signal</td>
</tr>
<tr>
<td>A1.T3.A1T3X001.GO+-O+</td>
<td>I 67.4</td>
<td>BOOL</td>
<td>Open/Closed valve … feedback signal</td>
</tr>
<tr>
<td>A1.T4.A1T4X003.GO+-O+</td>
<td>I 68.2</td>
<td>BOOL</td>
<td>Open/Closed valve … feedback signal</td>
</tr>
</tbody>
</table>
Standardized circuits for functional safety

- Replace the analog value A1.T2.A1T2L001.LISA+.M with a binary value which is the result of the comparison with 50 ml
- Functional table to design the combinatorial circuit

<table>
<thead>
<tr>
<th>A1T2L001 &gt; 50ml</th>
<th>A1T2X007</th>
<th>A1T3X001</th>
<th>A1T4X003</th>
<th>LOCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>0</td>
</tr>
<tr>
<td>x</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>x</td>
<td>x</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>x</td>
<td>1</td>
<td>x</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>x</td>
<td>x</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

- Result using conjunctive normal form (CNF) is used to lock the pump
Objectives

• Theory
  • Structure of a control loop
  • PID controller
  • Temperature control of the laboratory process cell

• Step-by-step instruction
  • Parameterization of a continuous controller
  • Output of the analog manipulated variable as a binary signal with a pulse generator
Structure of a control loop

- Process variables have to keep or achieve certain values
- Disturbance behavior: A certain value has to be kept in spite of disturbances
- Response to setpoint changes: Setpoint shall be achieved stable and dynamic

- Control loop works as follows:
  - Process variable is measured by sensor
  - Setpoint minus measured value calculates the system deviation
  - Controller calculates the manipulated variable of the actuator as a function of the deviation
  - Actuator has impact on the system
Control algorithm calculates the manipulated variable as a function of the deviation
Process industry uses the PID algorithm to 95%
  - P means proportional
    - Current manipulated variable only depends on current deviation
  - I means integral
    - Current manipulated variable depends on the sum of the last deviation values
  - D means differential
    - Current manipulated variable depends on the changes in the deviation value
Adjusting only three parameters (gain, reset time and derivative time)
Practical adjusting rules exists for systems without dominant dead times
  - Ziegler and Nichols method
  - Chien, Hrones and Reswick
Temperature control of the laboratory process cell

- **Control loop**
  - Process variable is A1.T2.A1T2T001.TIC.M
  - Manipulated variable is A1.T2.A1T2T001.TV.S
  - Setpoint is
    - Determined by recipe
    - Determined by operator
    - Locked
  - Conditions for locking
    - Level in the reactor has to be at least 200 ml
    - Temperature must not exceed 60°C
PA University Curriculums
Module 1 P01-07 Importing plant design data

Objectives

• Theory
  • Design of complex systems
  • Process tag type
  • Model

• Step-by-step instruction
  • Importing plant design data
  • Working with the process object view
  • Duplicating charts by creating process tag types/models
Design of complex systems

- Three general design methods
  - Principle of hierarchical structure
    - Plant hierarchy
  - Principle of modularization
    - Scope and complexity of blocks, CFC and SFC
  - Principle of reusing
    - Process tag types and models
- Reuse also implies
  - Use of proven solutions (standards)
  - Central modifiability
  - Tested implementation
Process tag types and models

- Process tag type (CFC) – corresponds to control module level
- Model (entire hierarchy) – corresponds to equipment module or unit level

<table>
<thead>
<tr>
<th>Level</th>
<th>Physical model</th>
<th>Interlock</th>
<th>Alarm management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process cell</td>
<td>Process cell</td>
<td>Interlock function for process cell X</td>
<td></td>
</tr>
<tr>
<td>Unit</td>
<td>Unit</td>
<td>Interlock function for unit X_XX</td>
<td>Alarm enabling/disabling for unit X_XX</td>
</tr>
<tr>
<td>Equipment module</td>
<td>Equipment module</td>
<td>Interlock function for equipment module XX_XXXX</td>
<td>Alarm enabling/disabling for equipment module XX_XXXX</td>
</tr>
<tr>
<td>Control module</td>
<td>Control module</td>
<td>Control module X_XX_XXXX</td>
<td></td>
</tr>
</tbody>
</table>
Process tag types and models of the laboratory process cell

• Selecting similar control modules
  • Pumps
    • A1T1P001, A1T1P002, A1T1P003 and A1T4P001
    • A1T2P001 and A1T2P002
  • Valves
    • A1T1V001, A1T1V002, A1T1V003, .. , A1T1V006
    • ...
• Selecting similar equipment modules
  • Tanks
    • A1T1B001, A1T1B002 and A1T1B003
    • A1T2R001 and A1T2R002
    • A1T3B001 and A1T3B002
Objective

- Theory
  - Structure of sequential function charts
  - Design of a sequential control system
  - Recipe of the laboratory process cell

- Step-by-step instruction
  - Creating and editing sequential function charts (SFC)
  - Connecting SFC and CFC
  - Testing the SFC
Structure of sequential function charts

• Alternating sequence of steps and transitions
  • First step: start step
  • Final step: end step

• Structures:
  • Unbranched sequential function chart
  • Alternative branches
  • Parallel branches

• Illegal structures:
  • Uncertain sequence – accessibility not assured
  • Partial deadlock – internal infinite loop
  • Total deadlock – no permitted step enabling condition

• One time or cyclical processing of sequential function chart is possible
Design of a sequential control system

- Approved design methods for sequential control systems
  - State transition diagram
    - Connected and directed graph
    - States shown as circle – can be linked with actions
    - State changes shown as arrows – can be connected to transition conditions
  - Petri nets
    - Consists of places and transitions
    - Places as circles
    - Transitions as rectangles/bars
    - Parallel sequences can be displayed
Recipe of the laboratory process cell


- When reactor A1.T2.R001 is filled, the liquid is to be heated to 25 °C with the agitator switched on.

- When reactor A1.T2.R002 is filled, 150ml from educt tank A1.T1.B001 is to be added to reactor A1.T2.R002. When this is completed, 10s later the agitator of reactor A1.T2.R002 is to be switched on.

- When the temperature of the liquid in reactor A1.T2.R001 has reached 25 °C, the mixture is to be pumped from reactor A1.T2.R002 to reactor A1.T2.R001.

- Now, the mixture in reactor A1.T2.R001 is to be heated to 28 °C and then drained into product tank A1.T3.B001.
PA University Curriculums  
Module 2 P02-01 HMI generation

Objectives

• Theory
  • Concepts of visualization
  • HMI generation in PCS 7
  • HMI of the laboratory process cell

• Step-by-step instruction
  • Generating the operator station (OS) in SIMATIC Manager
  • Configuration environment WinCC
  • Creating pictures with the Graphics Designer
PA University Curriculums
Module 2 P02-01 HMI generation

Concepts of visualization

- Important aspects of visualization
  - Organization of visualization
  - Print growth
  - Coding
  - Conspicuousness
  - Consistency
- Basic structure of display area according to VDI 3699
- Flowcharts
  - Process control flowcharts
  - Process flowcharts
    - Basic flowchart, process flowchart, P&ID flowchart
HMI generation in PCS 7

- Picture tree can be derived directly from plant hierarchy
  - Creating a picture in the corresponding level
- Using the block icons of templates
  - Deriving block icons from the plant hierarchy
- Configuring different OS areas
  - For example, unit T1 is monitored by operator 1, T2 to T4 by operator 2
- Monitor configuration
  - Visualization for different resolutions, numbers and arrangement of monitors
- Graphics Designer
  - Drawing the process pictures (static elements)
  - Linking dynamic elements with the process variables
PA University Curriculums
Module 2 P02-01 HMI generation

Graphics of the laboratory process cell

• Hierarchy includes level 1 and 2
  • A1_multipurpose_plant · A1_multipurpose_plant.pdf
    • A1_multipurpose_plant/T1_educt_tanks · T1_educt_tanks.pdf
    • A1_multipurpose_plant/T2_reaction · T2_reaction.pdf
    • A1_multipurpose_plant/T3_product_tanks · T3_product_tanks.pdf
    • A1_multipurpose_plant/T4_rinsing · T4_rinsing.pdf

• Plant display
  • Displays all units
  • Displays the most important information
  • Abstract

• Area display
  • Display of a unit
  • Display of faceplate icons of motors and valves
  • Display resembling the P&ID
Objectives

- Theory
  - Signaling systems
  - Alarms and messages
  - Alarm management in PCS 7

- Step-by-step instruction
  - Integration of monitoring and alarm blocks
  - Signaling system of WinCC
  - Display of alarms and warnings in the operator station (OS)
Signaling system, alarms and messages

- Interface between process and operator
- Early detection of deviations from the desired state
- Specific interventions to restore the desired state
- Alarm display or reporting occurrence of an event that requires immediate action of the operator
- Message display or reporting occurrence of an event that requires no immediate action of the operator

Properties for selection of alarms
- Relevant
- Unambiguous
- Timely
- Prioritized
- Comprehensible

<table>
<thead>
<tr>
<th>Response time</th>
<th>Potential effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plant shutdown</td>
</tr>
<tr>
<td>&lt; 5 min</td>
<td>High</td>
</tr>
<tr>
<td>5 - 20 min</td>
<td>Medium</td>
</tr>
<tr>
<td>&gt; 20 min</td>
<td>Low</td>
</tr>
</tbody>
</table>
Alarm management in PCS 7

- Function block for generating messages
- Picture icons to display alarm states
- Group alarms along the plant hierarchy
- Display and management of message lists
Alarms for the laboratory process cell

- Monitoring of levels
- Monitoring of temperatures
- Using MonAnS block (FB 1912) from Monitor folder of the PCS 7 Advanced Process Library V80
  - Monitoring a measurement value (analog signal)
  - Adjustable parameters
    - Warning limit (high/low)
    - Alarm limit (high/low)
- Display of faceplate icon
  - In unit T2_reaction
  - Positioning and compiling
Objectives

• Theory
  • Goals of archiving
  • Archiving on the OS server
  • Short-term and Long-term archiving
  • Trend reporting

• Step-by-step instruction
  • Activating archiving in CFC
  • Archive settings of the OS server
  • Curves and reports
PA University Curriculums
Module 2 P02-03 Archiving and Trend reporting

Goals of archiving

• Why must process data and events be logged?
  • **Rules and regulations:** logging of disturbance, verification of licensing requirements, consistent tracking of the production cycle
  • **Process management:** statistics of production data, optimization of production parameters, increasing of performance, optimization of material and manufacturing costs
  • **Safety:** analysis of production data for adapting production parameters especially limits and response time, verification of functional safety when testing interlocks and EMERGENCY OFF functions
  • **Performance:** increasing of performance of the process database, data backup
Archiving on the OS server

- Archiving on the OS server = short-term archiving
  - Process values
    - Slow cycle
      - Tag logging slow
    - Fast cycle
      - Tag logging fast
    - Messages/events
      - Alarm logging
  - Structure of the archives (Tag logging slow/fast, Alarm logging)
  - Cycling logging consists of segments

- 30 bytes/value
- max. 30 bytes/value
- 200 to 400 bytes/message
Short-term and long-term archiving

- Short-term archiving on the OS servers
- Long-term archiving on the Central Archive Server
- Process values
- Messages/events
- Charge reports, OS reports

- Archive slow
- Archive fast
- Message archive
- Report archive

- Central Archive Server (CAS) gathers data for long-term archiving from different OS servers and Batch servers
- CAS can be configured as redundant for increased data security
- CAS has no connection to the automation system
Trend reporting

• Trend reporting = Visualization of process values in curves
  (which means a graphical visualization of process values
  in dependency of time)

• Visualization options in PCS 7
  • Trend groups
  • Online Trend Control
  • Online Function Control (not according to
    the definition of trends but displays process values
    depending on other process values)

• Visualization of archived variables by accessing the logs on the OS server
• Visualization of online variables by buffering the current process values
  • Used for process values that are not archived
  • Buffering only as long as the visualization is shown
PA University Curriculums
Usage

Theoretical and practical introduction to the process control engineering of a process plant – in general and with PCS 7 at the university/college level

Guided implementation based on the available projects or implementation of your own designs

Test the implementation in a simulated plant
PA University Curriculums for SIMATIC PCS 7

Outlook

Use of the documents in training/education

• As a lecture (= theory) with practice (= exercises) to design a solution and to implement the design in PCS 7
• As practical training (= exercises) to design a solution and to implement the design in PCS 7

or

• As self-study to implement projects with PCS 7
Thank you for your attention!

Siemens Automation Cooperates with Education

siemens.com/sce