applications & TOOLS

# APC Add-on-Products versus PCS 7-integrated APC-Functions

System Application
Hints for Practice and Differentiation

SIEMENS

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# Preface

## Objective of the Application

Besides the APC functions in the SIMATIC PCS 7 APC Library respectively Advanced Process Library there are some more APC software packages in the PCS 7 add-on catalogue (available on www.automation.siemens.com):

- INCA: Model based predictive multivariable controller
- Presto: Softsensors for quantities not directly measurable
- RaPID: Expert tool for optimization of PID controllers
- ADCO: permanent adaptive controller
- Matlab/Simulink-DDE-Client: Online interface for APC
- FuzzyControl++: Engineering tool for fuzzy logic
- NeuroSystems: Engineering tool for artificial neural networks

Some functionalities, like e.g. fuzzy logic or adaptive control can be realized only with an Add-on product. On the other hand, in the areas of PID optimization, neural networks and predictive control, the customer has the choice between an add-on product and an APC function already included in PCS 7.

The following contribution is intended to support taking the appropriate decision, considering the setting of a task, the desired function range (set of features) and the non-functional requirements.

The illustrations added provide a visual impression of the graphical user interfaces of the software tools. As opposed to the other application notes, they are not intended to be a step-by-step manual for the application of the software. More detailed information concerning features and usage of the software tools can be found in the original documentation of the respective products.

## Main Contents of this Application

The following main points are discussed in this application note:

- Optimization of PID controllers: RaPID by Ipcos versus PCS 7 PID-Tuner.
- Softsensors based on artificial neural networks: Presto by Ipcos versus SIMATIC NeuroSystems.
- Model based predictive control: INCA by Ipcos versus PCS 7 ModPreCon.

## Validity

… valid for PCS 7 V7.0 SP1 and V7.1

**Reference to Industry Automation and Drives Service & Support**

This article is from the internet application portal of the Industry Automation and Drive Technologies Service & Support. Clicking the link below directly displays the download page of this document.

http://support.automation.siemens.com/WW/view/de/37361131

# Table of Contents

# 1 Introduction

**Note**

A general overview of the PCS 7-embedded APC functions (Advanced Process Control) is provided by the White Paper „How to Improve the Performance of your Plant Using the Appropriate Tools of SIMATIC PCS 7 APC-Portfolio?“

http://pcs.khe.siemens.com/efiles/PCS 7/support/marktstudien/WP_PCS 7_APC_EN.pdf

### SIMATIC PCS 7 Add-on-Catalogue

The modularity, flexibility, scalability and openness of SIMATIC PCS 7 offers ideal conditions for integrating additional components and solutions into the process control system and completing and extending their functionality in this way.

Since SIMATIC PCS 7 was launched on the market, we at Siemens as well as our external partners have developed a host of supplementary components that we refer to in short as PCS 7 add-ons.

The catalogue is available in the internet via the IA&DT mall:

https://mall.automation.siemens.com/DE/guest/index.asp?aktprim=0&nodeID=10008888&lang=en&foldersopen=-1303-1300-1-8523-8524-8525-8745-4545-&jumpto=8745

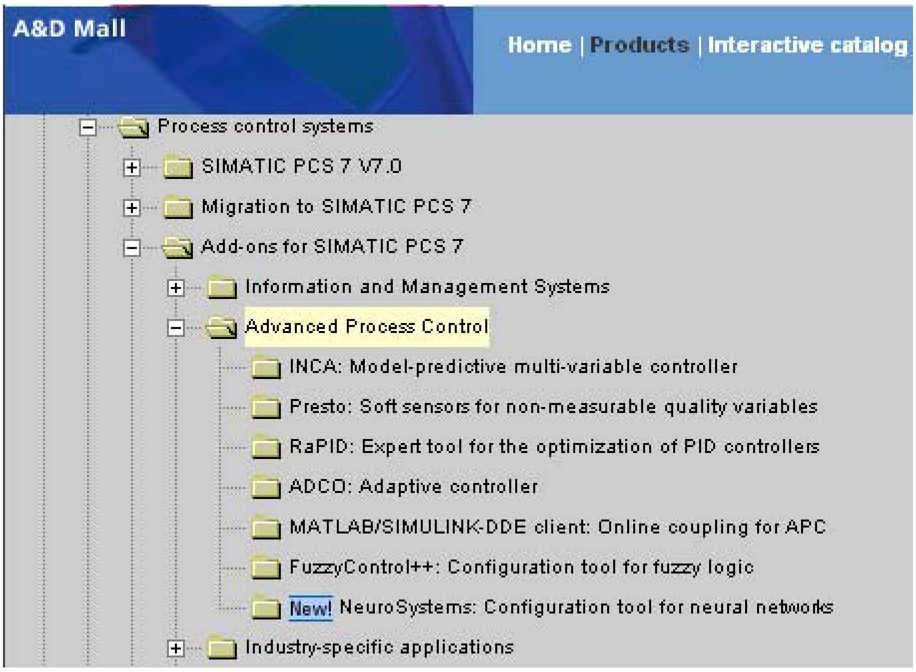
The responsibility for a PCS 7 add-on product generally rests with the appropriate product manager. External SIMATIC PCS 7 partners organize the sale and delivery of their products independently. Their own terms and conditions of business and delivery apply.

In the add-on catalogue, section „Advanced Process Control“, you will find the software packages shown in **Figure 1-1**.

In the following areas of APC methods the customer in principle has the choice between an add-on product and an APC function already included in PCS 7:

- Optimization of PID controllers: RaPID by Ipcos versus PCS 7 PID-Tuner.
- Softsensors based on artificial neural networks: Presto by Ipcos versus SIMATIC NeuroSystems.
- Model based predictive control: INCA by Ipcos versus PCS 7 ModPreCon.

Figure 1-1: Detail from the interactive catalogue of the IA&DT-Mall



# 2 Optimization of PID controllers: RaPID by Ipcos versus SIMATIC PCS 7 PID-Tuner

Many PID-controllers in industry are tuned by trial-and-error methods or by heuristic rules, and the differential action is frequently not considered at all. For certain standard control loops like the flow control of fluids with a proportional valve, there are empirical values for standard parameter sets. For slow controlled processes like temperature control loops, an optimization by trial-and-error takes too much time, because the observation of a single step response may need several hours.

Consequently the application of computer-aided controller design tools is winning recognition. The systematic optimization of the subordinate PID controllers has to be performed before any supervisory MPC can be applied, because the slave closed loops are part of the (time-invariant) process model used in the MPC master controller, and cannot be re-tuned later on.

The principle sequence of steps for computer-aided controller design stays the same from PID to MPC. The process is excited with a step of the manipulated variable or a setpoint step (if there is at least a stable but suboptimal controller setting). A dynamic process model is estimated from the stored measurement data by the tuning tool, i.e. the process parameters are calculated such that the learning data are fitted optimally (in a least squares sense) by the model. The calculation of the optimal controller parameters is based on the identified process model.

## 2.1 Comparison in a Table

### Optimization of PID Controllers

Table 2-1: Product Information

| | INCA PID-Tuner alias RaPID (“Robust Advanced PID Control”) | SIMATIC PCS 7 PID-Tuner |
|---|---|---|
| Software producer | IPCOS NV Leuven/Belgium and Boxtel/Netherlands http://www.ipcos.be | Siemens AG, I IA AS |
| Form of delivery | External product in add-on-catalogue | Since V7.0 integral part of PCS 7 toolset (before: option package with extra charge) |

Table 2-2: System architecture

| | INCA PID-Tuner alias RaPID (“Robust Advanced PID Control”) | SIMATIC PCS 7 PID-Tuner |
|---|---|---|
| Integration in PCS 7 | Separate software tool on external PC | Integral part of PCS 7-ES |



Table 2-3: Usability

| | INCA PID-Tuner alias RaPID (“Robust Advanced PID Control”) | SIMATIC PCS 7 PID-Tuner |
|---|---|---|
| Call | Windows start menu | Via context menu in CFC of PID controller |
| Coordination of tuning tool and plant operator | • No support by tool.<br>• Process excitation is operated manually in faceplate of controller, or excitation signals are read from a file. | • Tick mark „Enable Optimization“ in PID faceplate.<br>• During process excitation, the PID block is „remote controlled” by tuner software. |
| User guidance | Interactive Windows program with numerous menus and numerous user specified parameters | Software assistant (“wizard”) with pre-specified sequence of steps.<br>Number of parameters to be specified by user is minimized. |

Table 2-4: Functionality

| | **INCA PID-Tuner alias RaPID ("Robust Advanced PID Control")** | **SIMATIC PCS 7 PID-Tuner** |
|---|---|---|
| Controller types | Independent of DCS.<br>Predefined templates for common PID algorithms by Siemens, ABB, Honeywell, Emerson, etc. The appropriate structure has to be manually selected. | PID function blocks from PCS 7 Standard Library and Advanced Process Library are supported automatically. With V7.0 or higher, there is also an interface for different but similar function blocks from 3rd party libraries. |
| Data acquisition | OPC interface to PCS 7-Operator Station or offline evaluation of measurement data files | Trend curve recorder integrated in tuner assistant |
| Test signals | • Setpoint step<br>• Manipulated variable step<br>• Ramps<br>• Pseudo random binary noise signals (PRBNS) | • Setpoint step<br>• Manipulated variable step |
| Data pre-processing | • Select time slots<br>• Filter data | None |
| System identification | Selection of different model types with/without deadtime, system order to be selected arbitrarily. | PTn-models only, system order is determined automatically, deadtimes are approximated by higher system order. |
| Prior knowledge about the plant | … can be applied in the design | … is not necessary, but there is also no way to apply it inside the tool. |
| Verification of process model | „Model fit“ | Available since V7.0 |
| Controller design | Mathematical parameter optimization using simulated scenarios for setpoint following or disturbance rejection, allows well defined specification of requirements. | P/PI/PID according to standard formula of modulus optimum (→optimal disturbance rejection).<br>Optional: detuning of setpoint response. |
| Simulation of control loop | Can be fully parameterized.<br>Exact quantitative evaluation of results, comparison of different control designs, additional frequency domain analysis. | Fixed pre-defined scenario.<br>(Simulation available since V7.0) |
| Transfer of controller parameters | Manual input at Operator Station and CFC | Loading into AS and offline data management of CFC via mouse-click |

**Literature:**


- http://www.ipcos.com/cms/uploads/INCA%20PID%20Tuner.pdf
- Ipcos User Manual RaPID, Jan. 2007.
- Siemens PCS 7 PID-Tuner Online-Help V7.0.1, Nov. 2007.

## 2.2 Illustrations for RaPID

Figure 2-1: RaPID user interface

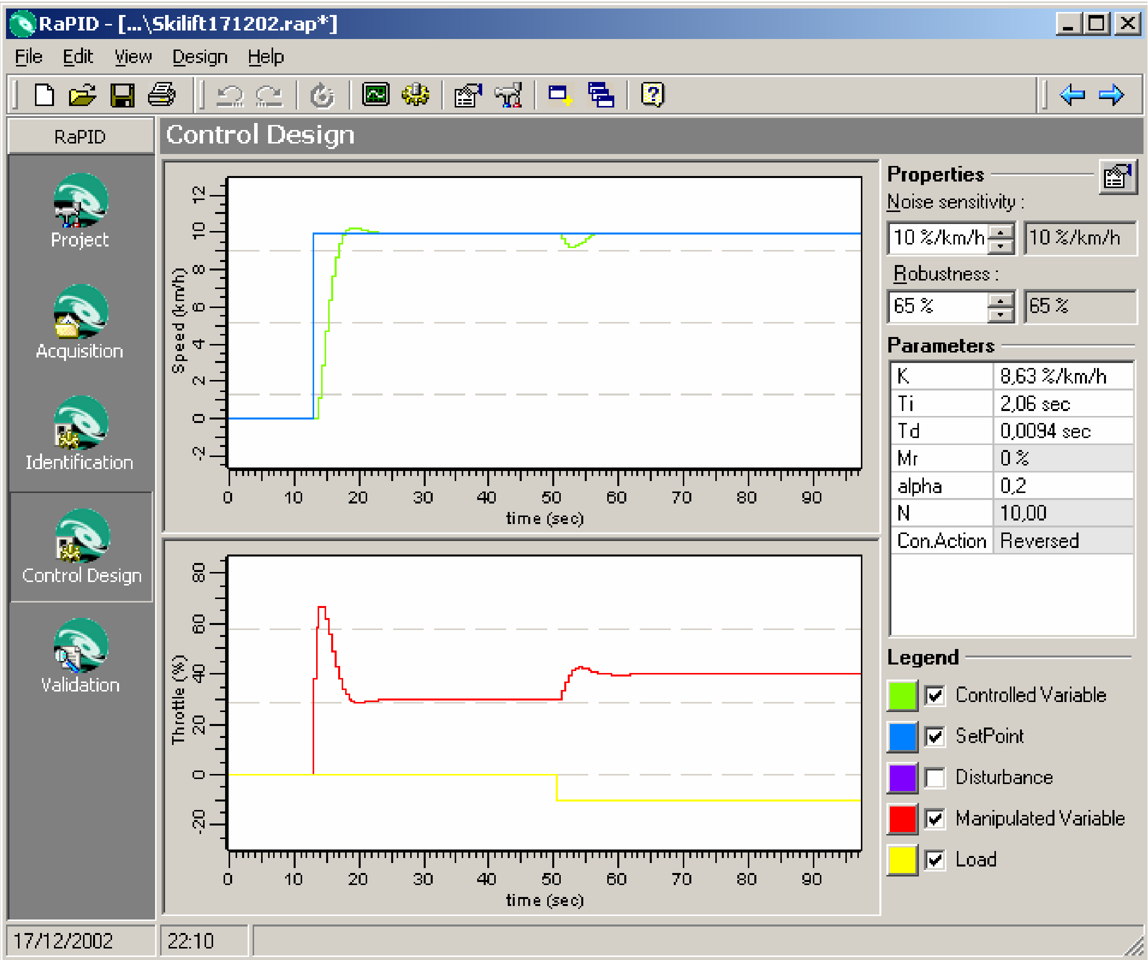


Figure 2-2: Process model in RaPID

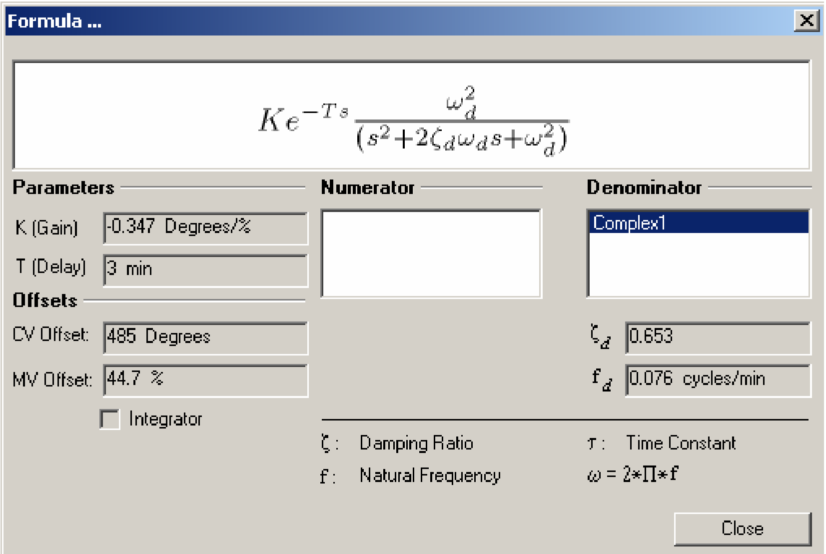



Figure 2-3: Selection of different controller types in RaPID

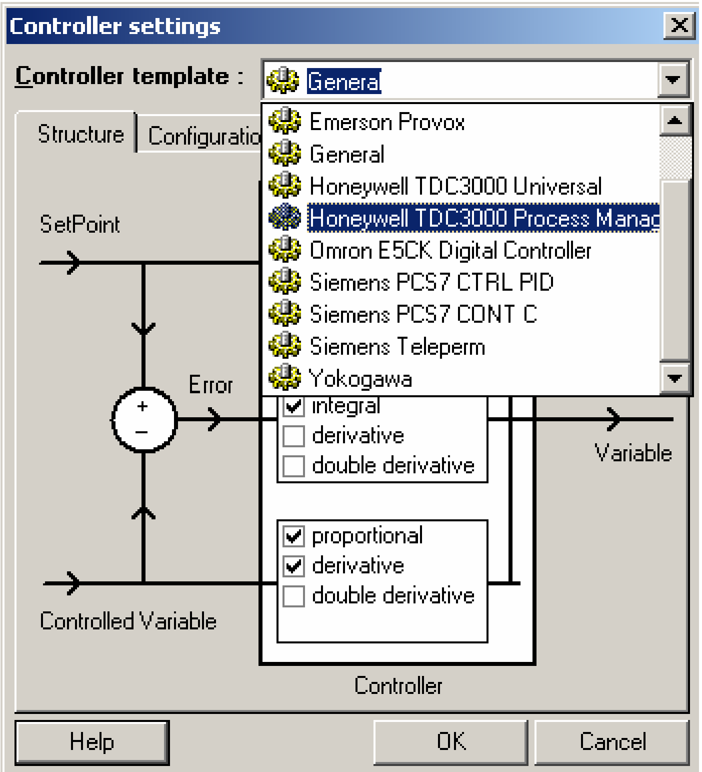
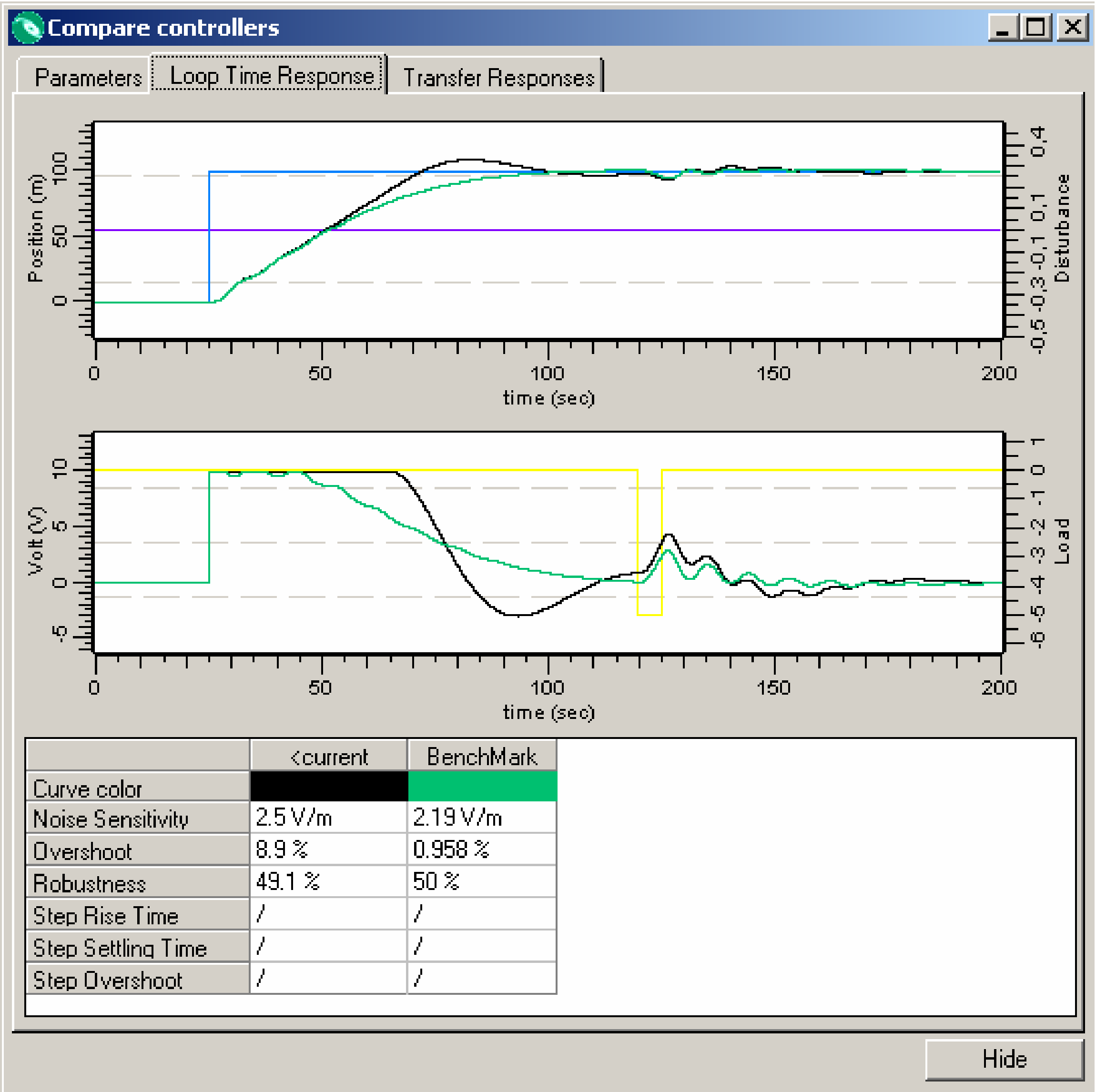
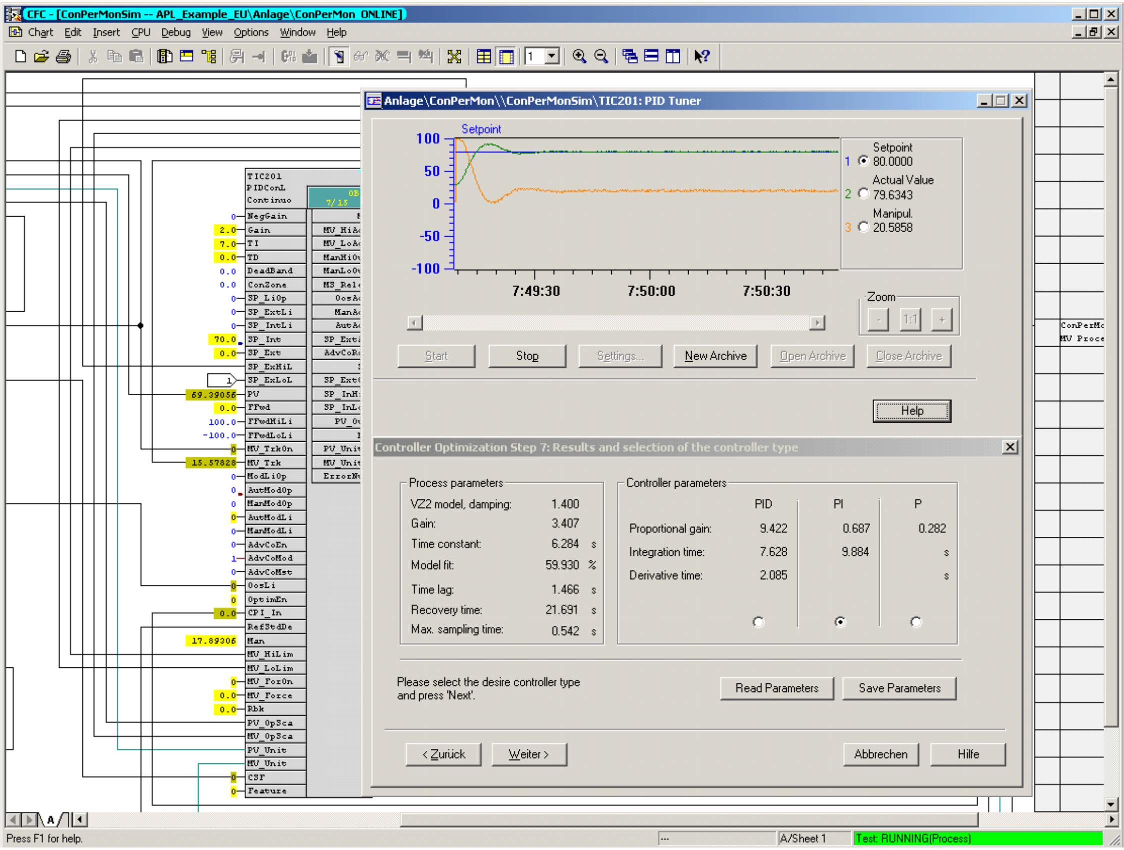


Figure 2-4: Comparison of different control designs in RaPID



## 2.3 Illustrations for PID-Tuner

Figure 2-5: PCS 7 PID-Tuner in CFC



## 2.4 Hints for Selection of Appropriate Product

### 2.4.1 Arguments for Application of PID-Tuner

- Seamless integration in PCS 7.
- No software license costs.
- Lower engineering costs.
- If the requirements for the application of PCS 7 PID-Tuners are fulfilled, and you are satisfied with the tuning results, you don’t need RaPID.
- RaPID is a tool „from experts for experts“, i.e. RaPID can be successfully applied only by control engineering specialists with the appropriate theoretical background. RaPID takes some time to get familiar with the software – the manual contains more than 100 pages and is available in English only.

### 2.4.2 Arguments for the Application of RaPID

- If you are using an older PCS 7-Version (<V7.0), and PID function blocks, that are not part of the Standard Library of PCS 7, RaPID is recommended, because the PID-Tuner of older versions is only applicable to standard PID function blocks of the PCS 7 Library. In principle, any 3rd-party PID tuning tools could be applied.

The following reasons might justify the purchasing and application of RaPID in special situations, although the PCS 7 PID-Tuner is also applicable:

- You impose very precise requirements how the controller should work in certain situations, i.e. you want to design and optimize the controller for a well-defined disturbance scenario, or for a well-defined setpoint trajectory (e.g. a typical setpoint step “from x to y”)
- You impose very special requirements with respect to robustness of the control loop (gain and phase margin), or the noise sensitivity (controller gain at high frequencies). RaPID allows for detailed specifications with respect to controller optimization.
- You are dealing with controlled plants showing extraordinary dynamical behavior, e.g. plants that are already oscillating without feedback control, or show non-minimum-phase behavior, i.e. after a manipulated variable command, they start running in the opposed direction first.
- You require especially high control performance, and are therefore prepared to spend a lot of time for the fine-tuning of individual control loops. As a tool „from experts for experts“, RaPID offers a lot of features, functions and tuning parameters.

# 3 Soft Sensors Based on Artificial Neural Networks: Presto by Ipcos versus SIMATIC NeuroSystems

Many process engineering plants suffer from the fact, that for important quality parameters of intermediate or end products, there are currently no low-cost, low-maintenance, reliable and fast sensors available on the market. The application of online analyzers or the execution of laboratory analyses is expensive, and even worse, it takes time, so that it is typically too late for efficient control actions to achieve the desired specifications. The application of model based estimation methods is an alternative solution in such cases, because they make use of process values that can be directly and easily measured, in order to predict quality parameters. This requires the existence of an appropriate process model that describes the correlation of these variables. In literature, this approach is called “soft sensor”, “virtual online analyzer” or “property estimator”.

There are several methods to develop soft sensors. The best results can be achieved using theoretical process models, relying on physical, thermodynamical and chemical first principles. Unfortunately this approach is not feasible in many cases, because the cost for theoretical modeling is not justified with respect to the expected benefit.

Empirical modeling based on historical process data requires less effort; however it does not always succeed. The disadvantage is that such models in soft sensors are valid only in this operation region, where process data are available in sufficient amount and quality, because extrapolation capabilities of such model are very limited.

If the correlation between measurable process values and quality variables to be estimated is strongly nonlinear, the application of artificial neural networks for modeling is well established, because they don’t require to prespecify the exact mathematical structure of the nonlinearity. The structure of an artificial neural network roughly resembles the structure of biological brains, involving a huge number of neurons and interconnections, where the knowledge about the detailed correlation is stored in the connection weights.

## 3.1 Comparison in a Table

### Soft sensors based on artificial neural networks

Table 3-1: Product Information

| | INCA Sensor alias Presto (“Properties Estimator”) | SIMATIC NeuroSystems |
|---|---|---|
| Software provider | IPCOS NV Leuven / Belgium and Boxtel / Netherlands http://www.ipcos.be | Siemens AG, I IS Erlangen |
| Delivery form | External product in add-on-catalogue | Siemens product in add-on catalogue |

Table 3-2: System architecture

| | INCA Sensor alias Presto (“Properties Estimator”) | SIMATIC NeuroSystems |
|---|---|---|
| Integration in PCS 7 | Separate software tool on external PC | Optional software tool in PCS 7-ES |
| Runtime algorithm | PrestoOnline as OPC DA-Client on Windows-PC with connection to Operator Station, requires typically an Ipocs DataServer and Scheduler as runtime environment. A PCS 7 function block with corresponding data structure in the OS, e.g. OpAnL is used as an interface in the WinCC OPC Server.<br>The runtime software does not require a lot of computing power and can be installed directly on an OS-client. | CFC-ready SIMATIC function block NEURO_64K.<br>The runtime software does not require a lot of computing power, but an additional user date block for parameterization. |
| Availability | …of software on Windows PC is generally lower than in the central controller of a DCS.<br>Therefore supervision via watchdog is required. | …of runtime software is equivalent to conventional function blocks inside DCS, and moreover can make use of redundant AS hardware. |

Table 3-3: Usability

| | INCA Sensor alias Presto (“Properties Estimator”) | SIMATIC NeuroSystems |
|---|---|---|
| Call | Windows start menu | Via context menu in CFC of Neuro function block or via Windows start menu |
| User guidance in engineering tool | Interactive Windows program with numerous menus and numerous user specified parameters | Interactive Windows program with simple menus and a small number of user specified parameters |
| Operator monitoring and control during operating phase | Compact GUI of Presto Online including functions for input of lab sample results | Standardized PCS 7 faceplate |
| Transfer of configuration data to runtime algorithm | PrestoOffline creates *.csv-configuration file for PrestoOnline. | Parameters for the user data block of Neuro function block are supplied by NeuroSystems tool |



Table 3-4: Functionality

| | INCA Sensor alias Presto (“Properties Estimator”) | SIMATIC NeuroSystems |
|---|---|---|
| Number of inputs | Unlimited | ≤ 100, typically ≤ 8 |
| Number of outputs | Unlimited | ≤ 10, typically ≤ 4 |
| Data acquisition | • Offline evaluation of measurement data files: Excel, Text, Access etc.<br>• Data including time stamps, also suitable for dynamic models.<br>• Import of several data files is supported. | • Offline evaluation of measurement data files: Ascii-Text, tab delimited, in fixed format.<br>• Data without time stamps, because only static models are identified.<br>• Only one file for learning data, and optionally a second file for validation data. |
| Test signals | Have to be generated by user outside of tool. | Have to be generated by user outside of tool. |
| Data preprocessing offline | • Comprehensive statistic of raw data,<br>• Selection of time slots,<br>• Data filtering,<br>• De-Trending,<br>• Outlier elimination,<br>• Resampling of datasets with different sampling rates, | • Statistical distribution of learning date incl. Mean value and variance,<br>• Option for normalization of input- and output data based on learning data file.<br>For further data preprocessing, external tools like MS Excel or Matlab must applied. |

| | INCA Sensor alias Presto ("Properties Estimator") | SIMATIC NeuroSystems |
|---|---|---|
| | • Arithmetic operations,<br>• Automatic Normalization | |
| Selection of relevant input variables | Comparison of models with different structures, i.e. with different combinations of input variables.<br>Selection via genetic algorithms or „beam search". | Combination visualization of correlation of input and output signals.<br>Visualization of relevance of each input. |
| Modeling of dynamic systems | Dynamic model types or consideration of time-delayed inputs. | Only feasible using work-arounds: series connection of deadtime-blocks in front of individual input variables, estimation of deadtimes using external tools, manipulation of learning data to make them deadtime-free. |
| System identification | Selection of different model types:<br>• Linear transfer functions<br>• General non-linear Models (GNOMOs)<br>• Fuzzy logic<br>• Partial least squares estimators | Three types of artificial neural networks:<br>• Mulitlayer-perceptron<br>• RBF network (radial basis functions)<br>• Neuro-fuzzy system |
| Prior knowledge about the plant | … can be applied in the design. | … is not necessary, but there is also no way to apply it inside the tool (besides the selection of input variables). |
| Verification of process models | • Comparison of model output and measured data in trend curve.<br>• Individual time slots can be declared to be learning or validation data. The statistical evaluation of models can be based on learning and/or validation data.<br>• Further graphical evaluations: scatterplot, residual analysis. | • Comparison of model output and measured data in trend curve.<br>• Validation data can be read from a separate data file, or selected stochastically from the learning data.<br>• Animated 3D graphics (characteristic surface). |
| Data preprocessing online | Inside OPC client incl. Outlier detection („peak shaving"). | Can be realized using standard CFC function blocks (e.g. Smooth). |
| Alignment with laboratory measurement results | Bias update module. | …is missing. |

| | INCA Sensor alias Presto ("Properties Estimator") | SIMATIC NeuroSystems |
|---|---|---|
| Information regarding reliability of calculation results | Confidence intervals for calculated output values | …are missing. |
| Alarming | Inside Ipcos environment, i.e. outside of DCS. If needed, an additional alarming inside of DCS can be realized with additional CFC function blocks. | Can be realized with standard CFC function blocks (e.g. MonAnL). |

**Literature:**


- http://www.ipcos.com/cms/uploads/INCA%20Sensor.pdf
- Ipcos user manual Presto, 2007
- User manual SIMATIC NeuroSystems V5.1, Siemens AG, 2008
- Contact (product manager NeuroSystems): Langer, Gerhard; Industry Sector, I IS IN E&C OC IT PRODUCTS, Erlangen
- Dittmar, R: Vergleich von Werkzeugen zur Entwicklung von Soft-Sensoren auf der Grundlage künstlicher neuronaler Netze. Studie im Auftrag von A&D GT 5 (B-M. Pfeiffer), FH Westküste, Heide/Holstein, August 2001.

## 3.2 Illustrations for Presto

Figure 3-1: System architecture for external soft sensor Presto

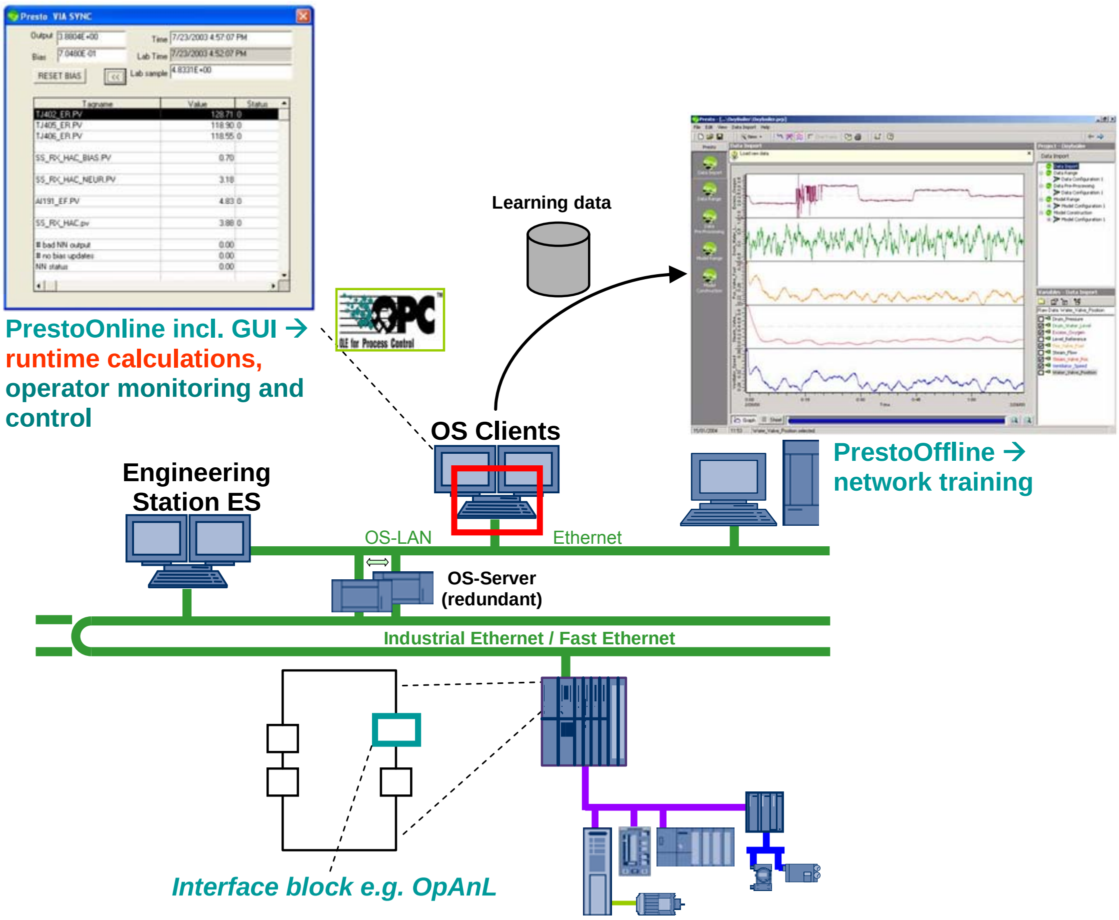
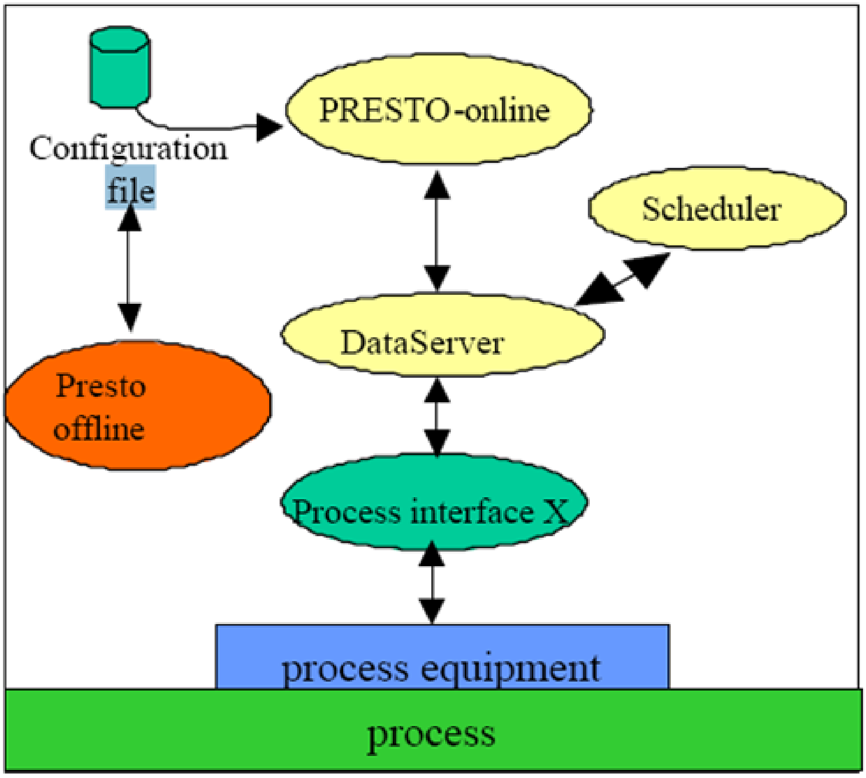
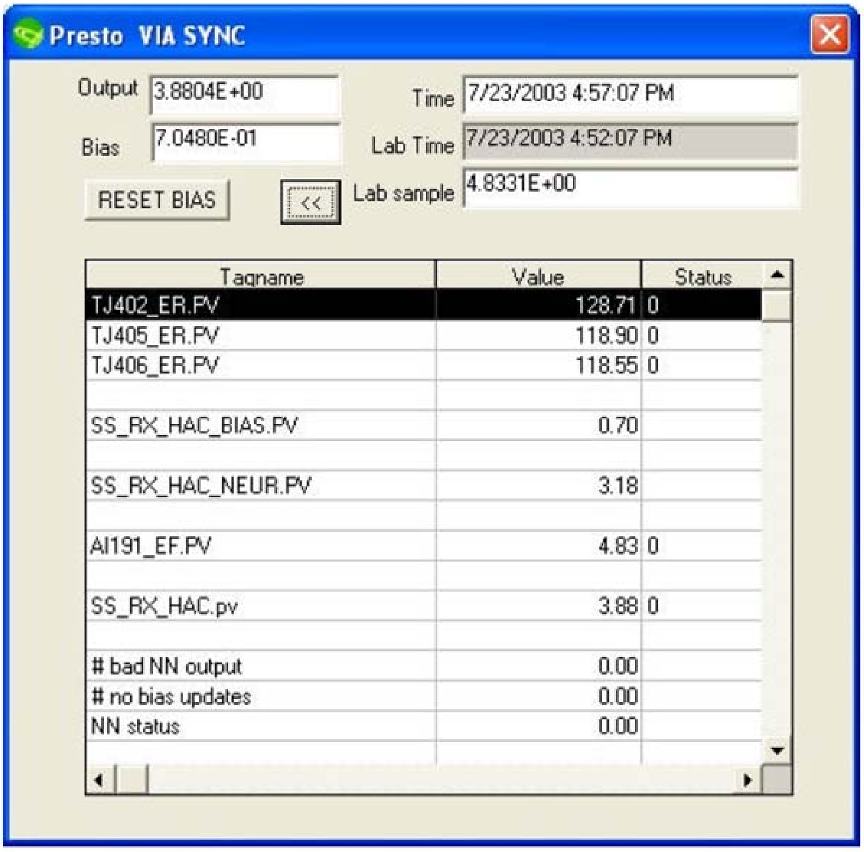


Figure 3-2: Software structure of Presto




The so called „DataServer“ is an Ipcos-internal OPC server, that is connected via an „OPC delegator“ to the "process interface", i.e. the OPC server of an OS-Client.

Figure 3-3: GUI of PrestoOnline



## 3.3 Illustrations for NeuroSystems

Figure 3-4: System architecture for SIMATIC NeuroSystems

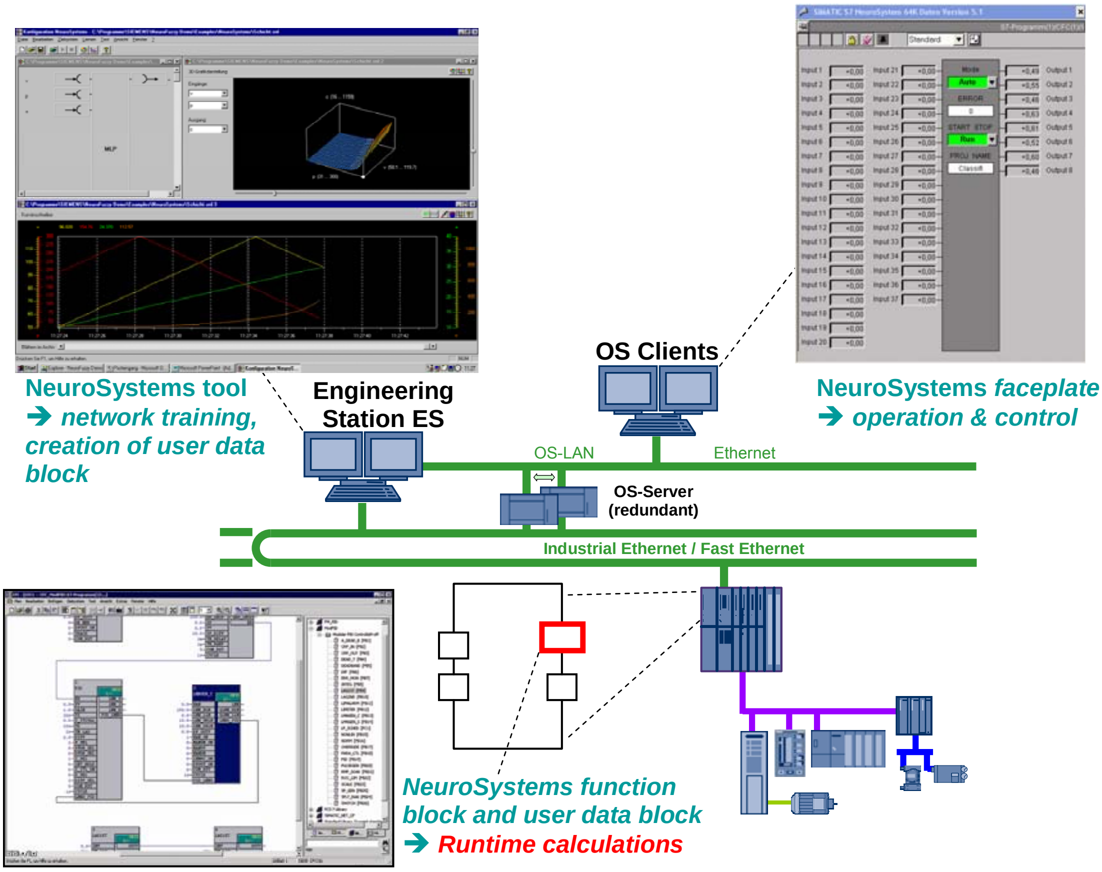


Figure 3-5: Function block NEURO_64K in SIMATIC CFC

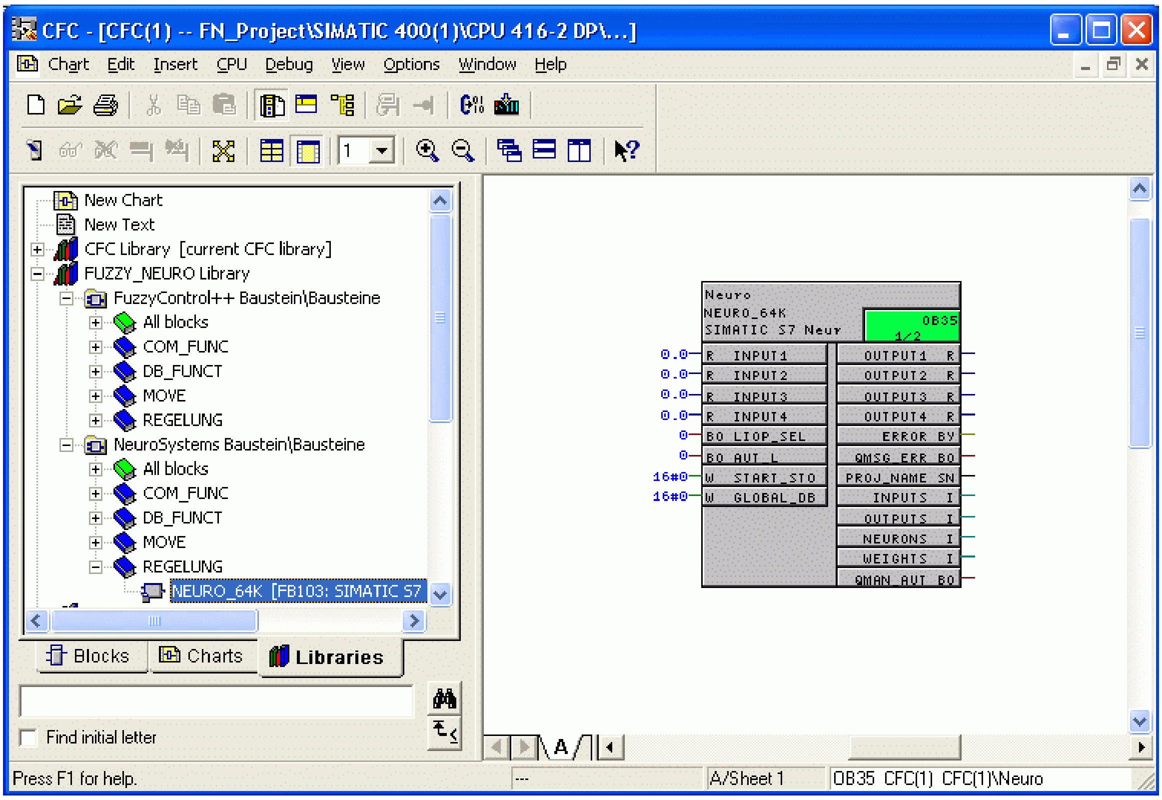


Figure 3-6: Faceplate of function block Neuro_64K

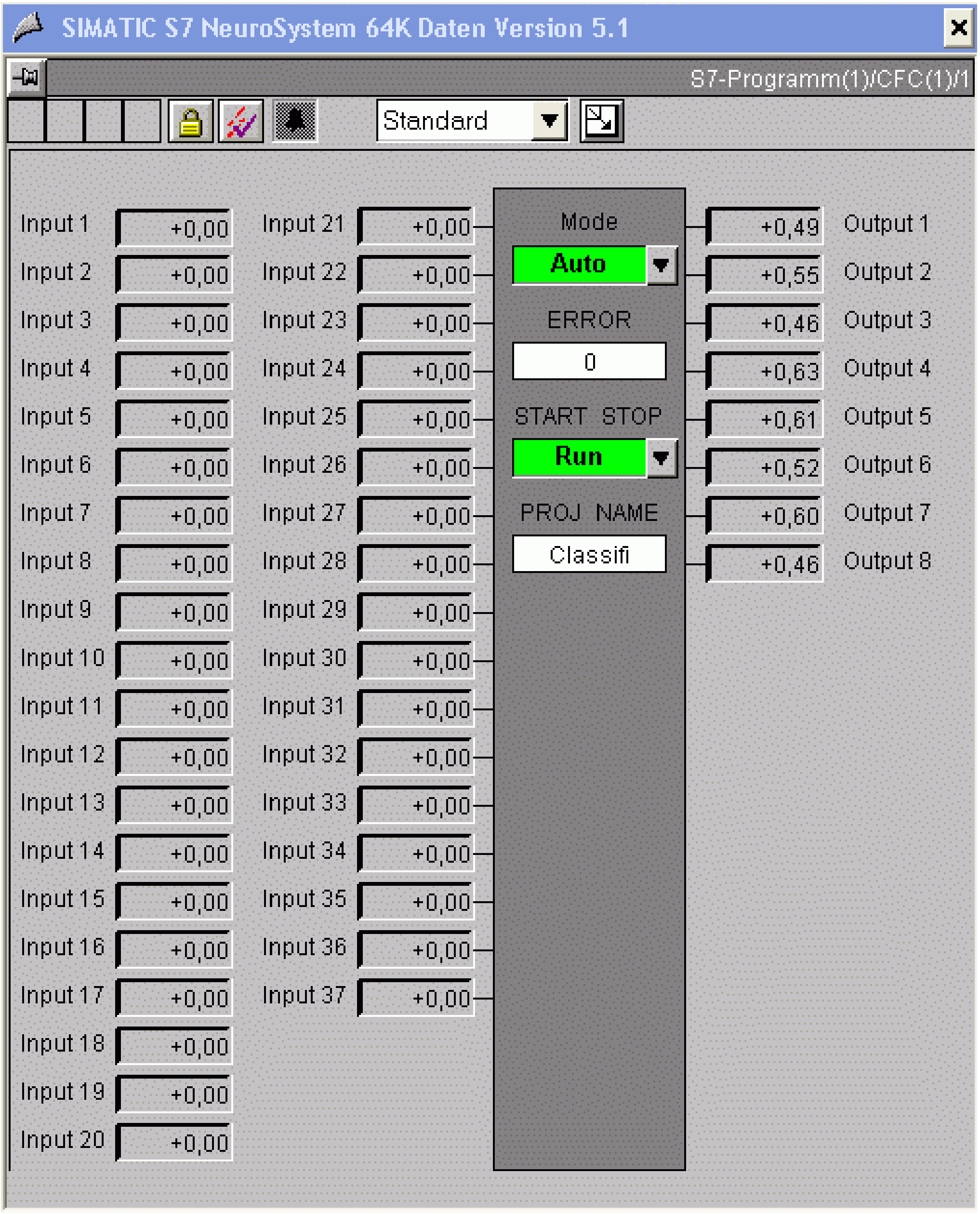
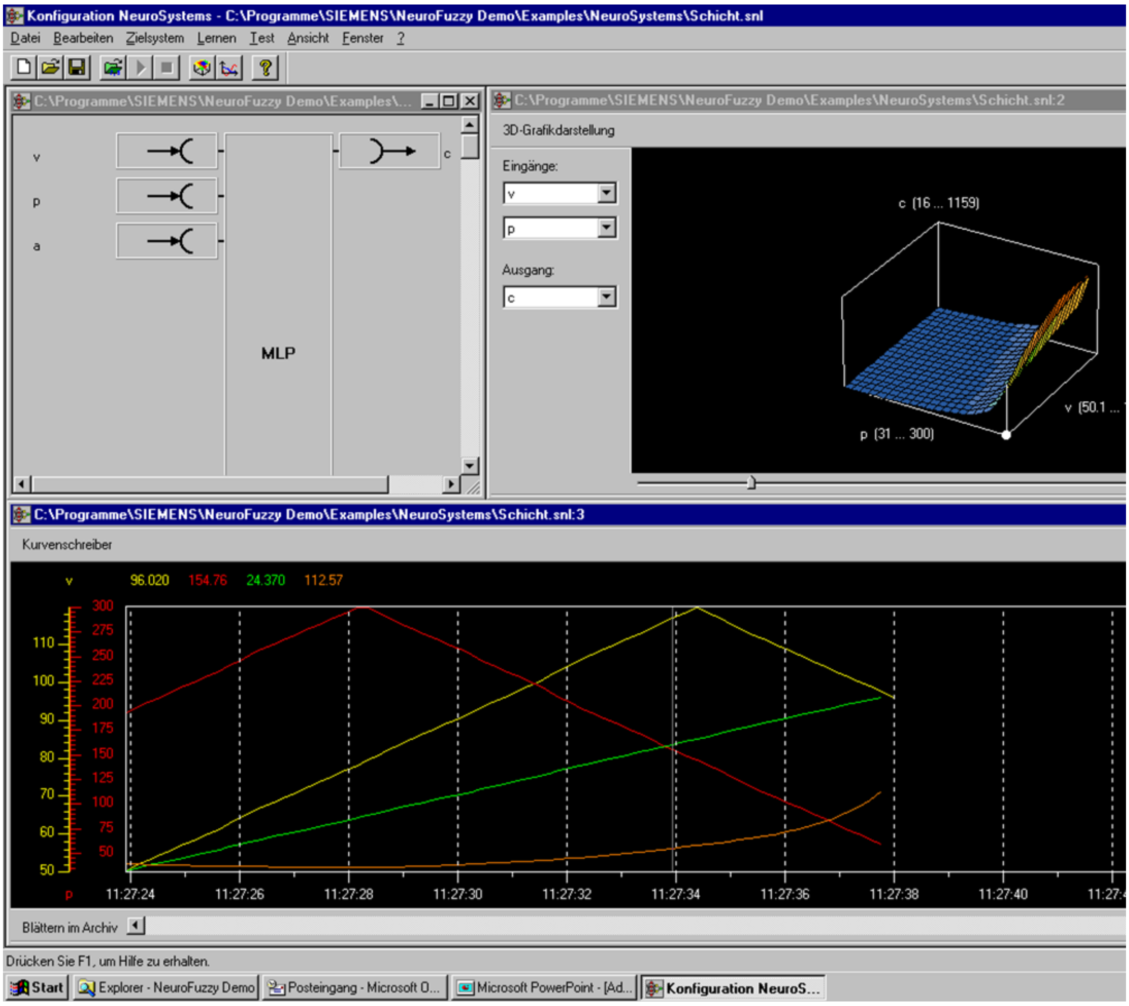


Figure 3-7: GUI of engineering tool NeuroSystems



## 3.4 Hints for Selection of Appropriate Product

### 3.4.1 Arguments for Application of NeuroSystems

- Higher availability of runtime algorithm in automation system, up to exploitation of redundant SIMATIC hardware.
- More easy integration in PCS 7.
- Less software and engineering costs.
- For Presto, the integration into the DCS and model engineering require an amount of effort similar to the application of an external model predictive controller (e.g. INCA in section 4).
- In general, the Ipcos tool is a tool „from experts for experts“ (similar to RaPID) and requires the appropriate time to get familiar with the software and the theory behind – while the less cost-intensive Siemens tool has advantages with respect to usability.
- For smaller soft sensor applications (static models with 2…5 input variables) SIMATIC NeuroSystems is completely sufficient.

### 3.4.2 Arguments for Application of Presto

- Only Presto is really prepared for the modeling of dynamic effects, i.e. for the identification of time delays between input and output variables. NeuroSystems in principal assumes a static characteristic surface, i.e. delay-free effects from the input variables to the output variables.
- For larger softsensor applications with numerous input variables, Presto offers advantages with respect to modeling features and model performance that can be achieved.
- As a tool „from experts for experts“ Presto offers a lot of functions and user definable parameters, and is promising very good results if applied by professionals.
- If the application of INCA (c.f. section 4) is planned anyway, the application of Presto suggests itself, because both tools work neatly together in a common runtime environment on a separate PC.

# 4 Model Based Predictive Control: INCA by Ipcos versus SIMATIC PCS 7 ModPreCon

Although there are a lot of different multivariable control algorithms in theory (e.g. state space controllers, $H_\infty$- controllers), the model predictive controllers (MPC) dominate the field in industry. Like suggested by the term "model based", a dynamic model of process behaviour including all interactions is used inside the control algorithm to predict future process movements in a defined time span. The control problem is interpreted and solved as an optimization problem. The optimal trajectory of the manipulated variables (MVs) minimizes both the sum of future control errors and the sum of future MV moves.

The following section is a typical example for the comparison of a DCS embedded "lean" MPC and an external "full-blown" MPC with online optimization, as discussed in general form in section 1.4 of the whitepaper cited above.

## 4.1 Comparison in a Table

### Model Predictive Control

Table 4-1 Product information

| | INCA MPC ("Ipcos Novel Controller Architecture") | SIMATIC PCS 7 MPC bzw. ModPreCon |
|---|---|---|
| Software provider | IPCOS NV Leuven/Belgium and Boxtel/Netherlands http://www.ipcos.be | Siemens AG, I IA AS |
| Delivery form | External product in add-on catalogue, is typically sold in conjunction with engineering services as "turnkey solution". | Since V7.0.1 integral part of PCS 7 toolset, as part of APC-Library respectively Advanced Process Library |

Table 4-2: System architecture

| | INCA MPC ("Ipcos Novel Controller Architecture") | SIMATIC PCS 7 MPC bzw. ModPreCon |
|---|---|---|
| Integration in PCS 7 | Separate software tool on external PC | PCS 7 function block with faceplate and configuration tool |
| Runtime algorithm | INCAEngine as OPC DA client on Windows-PC with connection to Operator Station, requires an Ipcos Data-Server and Scheduler as | PCS 7 function block MPC or ModPreCon.<br>The function block requires considerable computing power and a separate user |

| | INCA MPC ("Ipcos Novel Controller Architecture") | SIMATIC PCS 7 MPC bzw. ModPreCon |
|---|---|---|
| | runtime environment.<br>Dedicated APC interface function blocks are required as infrastructure in the AS. Those are provided by CC CG as re-usable solution.<br>Starting from PCS 7 V7.1, all controller blocks of the Advanced Process Library will provide dedicated interfaces for external APC software tools.<br>The controller runtime software requires a lot of computing power and must be installed on a separate PC. | data block for parameterization.<br>The function block can typically be called in low-priority cyclic task inside the SIMATIC controller. |
| Availability | …of software on Windows PC is generally lower than in the central controller of a DCS.<br>Therefore a conventional backup control strategy inside the DCS and supervision via watchdog is required. | …is equivalent to conventional controller function blocks inside DCS, and moreover can make use of redundant AS hardware. |

Table 4-3: Usability

| | INCA MPC ("Ipcos Novel Controller Architecture") | SIMATIC PCS 7 MPC bzw. ModPreCon |
|---|---|---|
| Call | Windows start menu | Via context menu in CFC of ModPreCon function block, or via Windows start menu |
| User guidance in engineering tool | Interactive Windows program INCA_Modeler with numerous menus and numerous user specified parameters | MPC configurator with predefined sequence of three working steps.<br>Number of parameters to be specified by user is minimized. |
| Operator monitoring and control during operating phase | GUI INCA_View with numerous possibilities for parameterization.<br>Online visualization of predictions. | Standardized PCS 7 Faceplate.<br>Look&feel similar to PID controller. |

Table 4-4: Functionality

| | INCA MPC ("Ipcos Novel Controller Architecture") | SIMATIC PCS 7 MPC bzw. ModPreCon |
|---|---|---|
| Number of controlled variables (CVs) | unlimited, typically 3..20<br>can be varying at runtime (become smaller). | $\leq 4$<br>constant at runtime. |
| Number of manipulated variables (MVs) | unlimited, typically 5..20<br>frequently not equal to number of CVs,<br>can be varying at runtime (become smaller). | $\leq 4$<br>usually equal to number of CVs,<br>can be varying at runtime (become smaller). |
| Number of disturbance variables (DVs) | unlimited, typically 0..5,<br>can be activated at runtime. | $\leq 1$<br>can be activated at runtime. |
| CV constraints | Control zones around setpoints („soft constraints") | Control zones around setpoints („soft constraints") |
| MV constraints | MV limits („hard constraints") | MV limits („hard constraints") |
| Control targets | CVxZone, CVxIdeal, CVxDynamic, MVxMovePenalty, MVxIdeal<br>each of them with rank and weight. | SPx±SPxDeadBand, MVxMovePenalty<br>each of them with weight. |
| Optimization | Online iterative solution of optimization problem in each sample step, considering constraints and hierarchy of control targets (ranks).<br>Algorithm: quadratic programming (QP-Solver). | Analytical solution of optimization problem ignoring constraints. This solution can be calculated offline based on performance index and process model, and delivers a mathematical formula that requires only a few matrix multiplications for the online calculation of MVs. |
| Test signals | Generation of special PRBNS test signals based on rough process model.<br>Test signals can be activated using an additional application called INCA_Test. | Typically a series of step experiments.<br>Test signals must be generated by user in manual mode of ModPreCon. |
| Data acquisition | …using INCA_Test. | …using trend curve recorder of CFC |
| Data preprocessing offline | • Selection of several time slots<br>• Low-pass filtering<br>• De-trending | • Selection of time slot<br>• Low-pass filtering<br>• De-trending |
| System identification | Numerous model forms, to be selected by user:<br>• Finite Impulse Response (FIR models) | Universal, fixed model type: ARX model of 4. order plus deadtime for each transfer channel. |

| | INCA MPC (“Ipcos Novel Controller Architecture”) | SIMATIC PCS 7 MPC bzw. ModPreCon |
|---|---|---|
| | • State space models (semi-automatic order selection using Hankel singular values)<br>• ARX models identified by output error minimization<br>• Laplace transfer functions in continuous time | Automatic conversion to Finite Step Response (FSR model) for controller. |
| Prior knowledge about the plant | … can be applied in the design. | … is not necessary, but there is also no way to apply it inside the tool. |
| Verification of process models | Comparison of model output and measured data in trend curve. | Comparison of model output and measured data in trend curve. |
| Controller design | …not explicitly required.<br>Numerous controller parameters can be adjusted online.<br>For Simulation there is a separate elaborate tool called INCA_Simulator. | …automatically in MPC configurator,<br>…requires the specification of CV weights and MV move penalties only.<br>…can easily be verified inside the configurator tool by simulation. |
| Handling of nonlinear processes | • Gain scheduling<br>• Trajectory control | • Model scheduling (solution template since PCS 7 V7.1)<br>• Trajectory control designated in ModPreCon function block, dedicated modeling and activation of trajectories currently still require applicative efforts. |
| Data preprocessing | In APC interface blocks or via Smooth function block. | Can be realized with standard CFC function blocks (e.g. Smooth). |
| Alarming | Inside Ipcos environment, i.e. outside of DCS, and additionally with APC interface blocks inside of DCS. | Can be realized with standard CFC function blocks (e.g. MonAnL). |

**Literature:**

- http://www.ipcos.com/cms/uploads/INCA%20MPC.pdf
- Ipcos user manual INCAEngine V7.1, Jan. 2007
- Siemens AG, Automation and Drives: Online-Help of PCS 7 APC-Library V7.0 SP 1, Nov. 2007.
- Siemens AG, Sektor Industry: Online-Help of PCS 7 Advanced Process Library V7.1, Mar. 2009.

## 4.2 Illustrations for INCA

Figure 4-1: System architecture for external „full-blown" predictive controller INCA

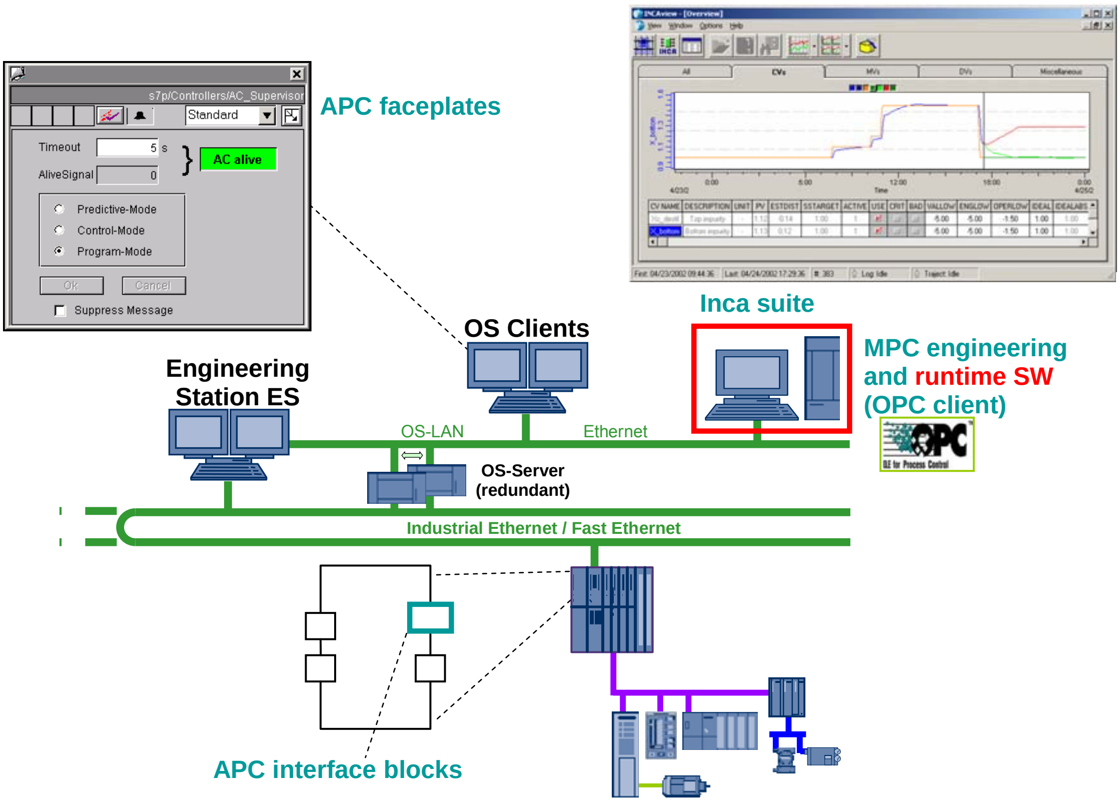
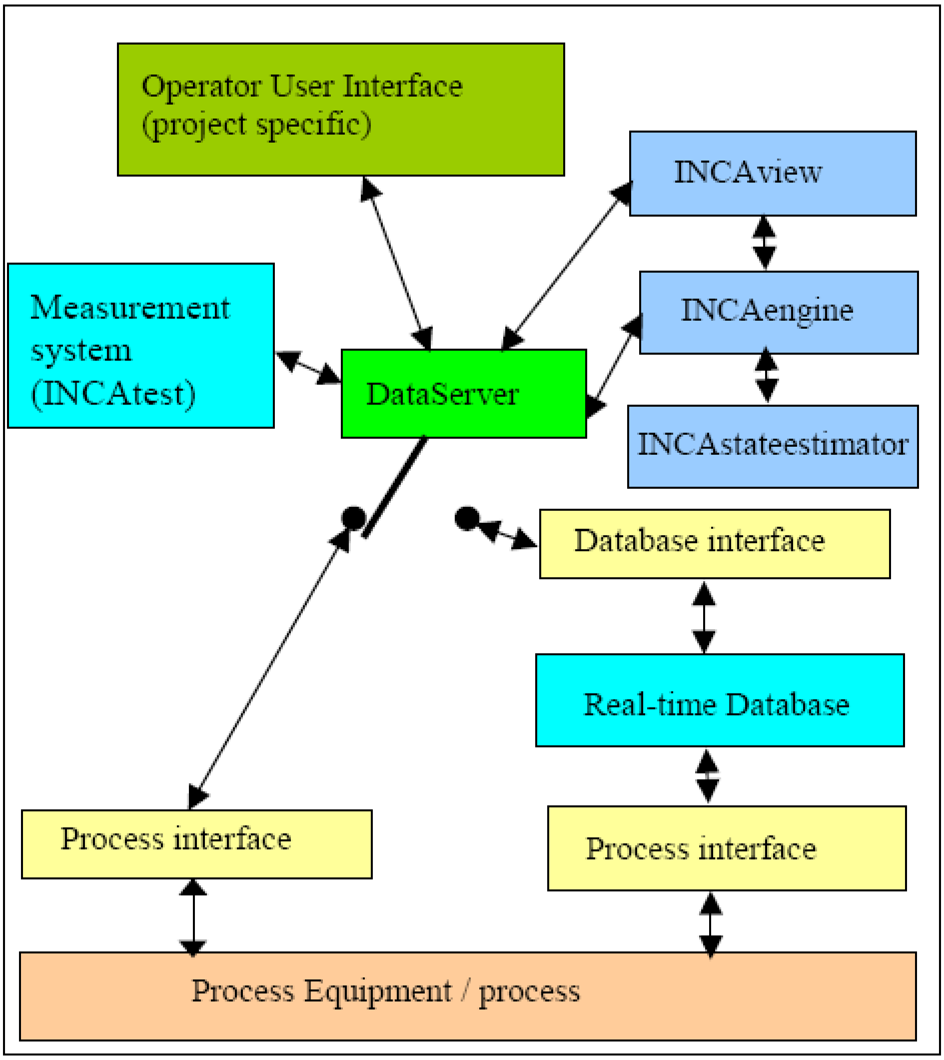


Figure 4-2: Software structure of INCA Suite




The so called „DataServer“ is an Ipcos-internal OPC server, that is connected via an „OPC delegator“ to the "process inferface", i.e. the OPC server of an OS-Client. The "projekt specific operator user interface" is realized using the APC faceplates on the OS. The alternative process connection via a database interface is not applied in the context of PCS 7.

Figure 4-3: Features and faceplates of the three APC interface function blocks

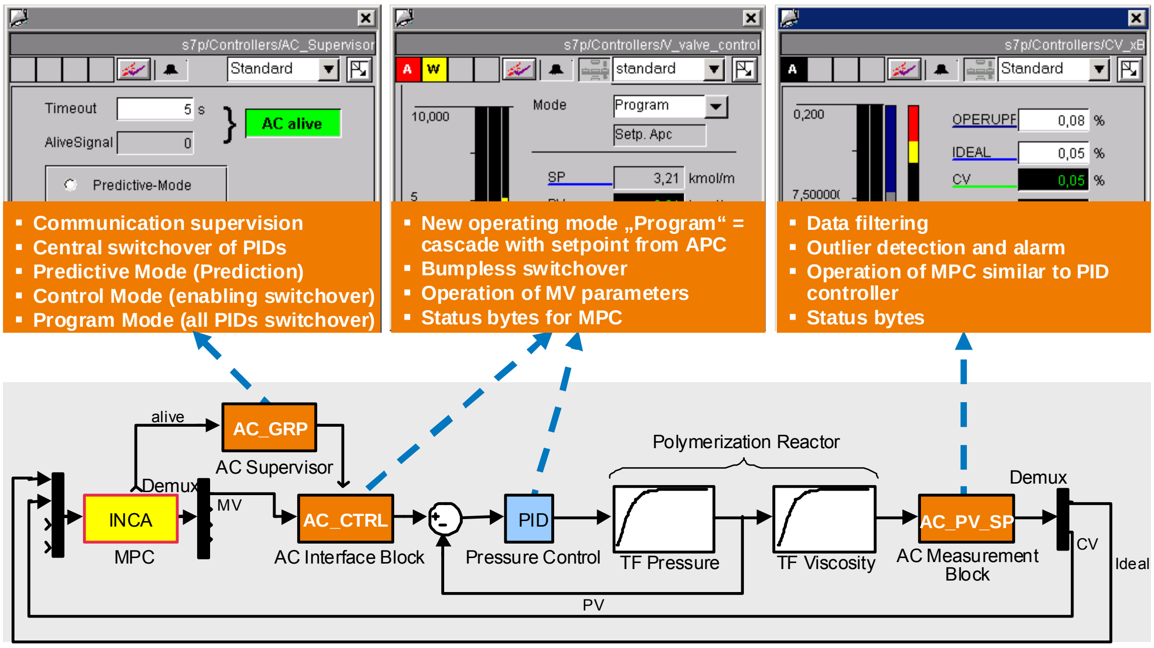
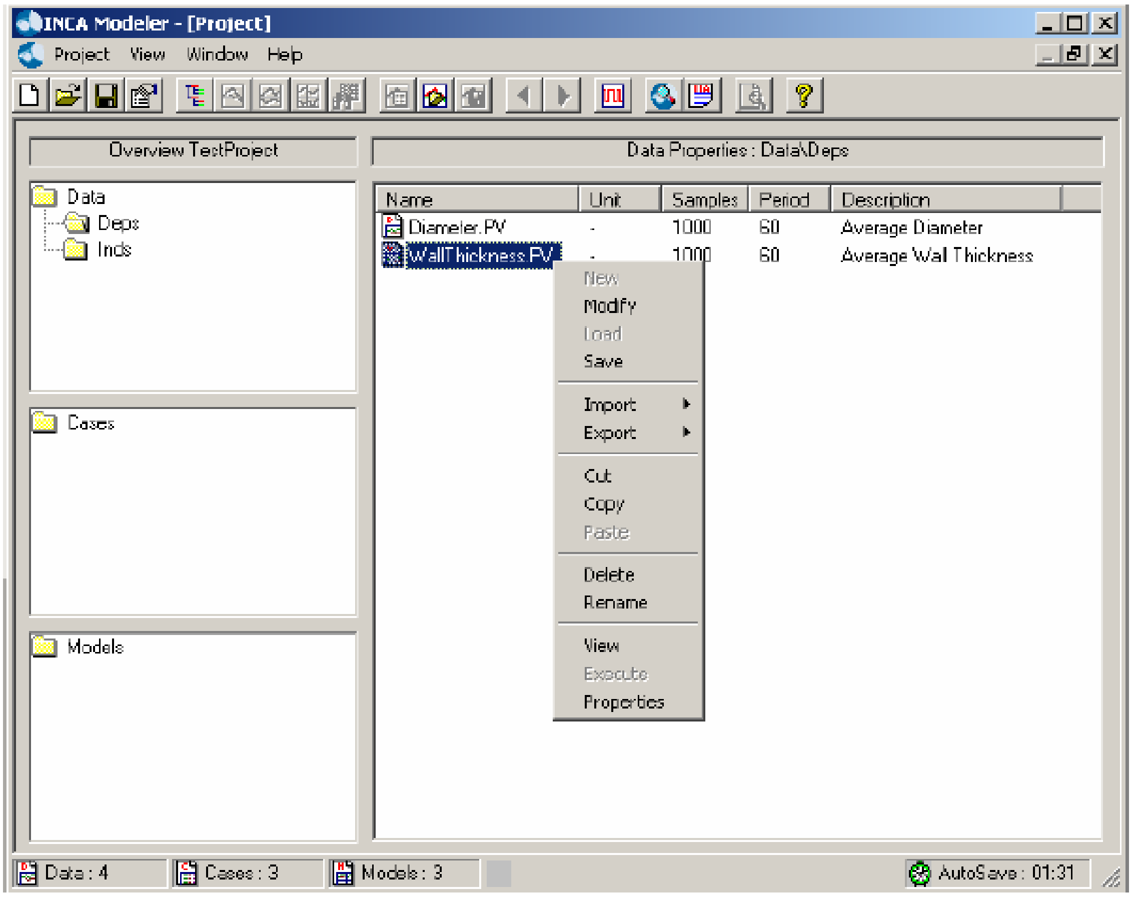



Figure 4-4: MPC graphical user interface INCA_View with online visualization of predictions

- Orange: setpoint
- blue: CV in the past
- red: prediction of free CV response if MVs are frozen
- green: planned optimal CV trajectory
- CVs: controlled variables
- MVs: manipulated variables
- DVs: disturbance variables

Figure 4-5: GUI of INCA_Modeler




In a modeling project, there are folders with data and models. A “case” is a combination of data and model structure, the execution of a case is the identification of model parameters from these data.

Figure 4-6: Comparison of two models in INCA_Modeler

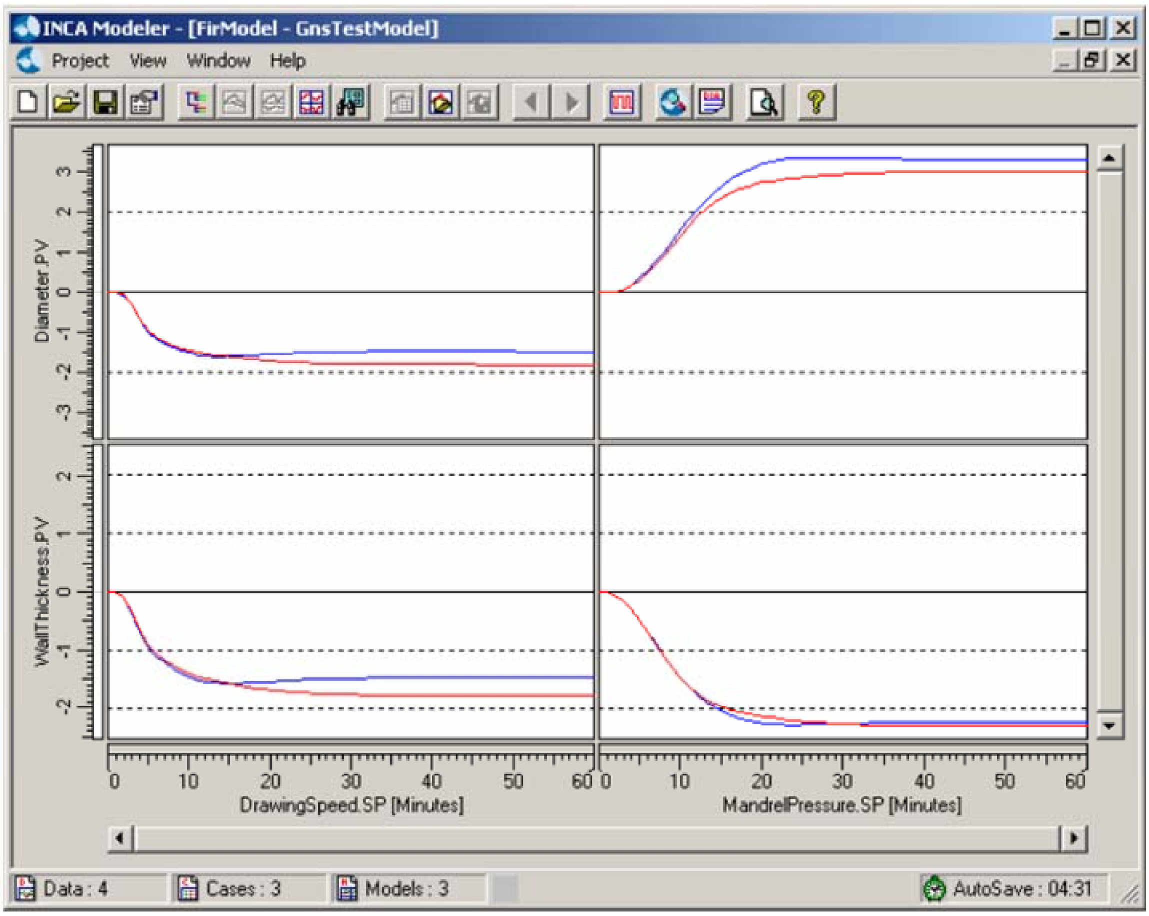
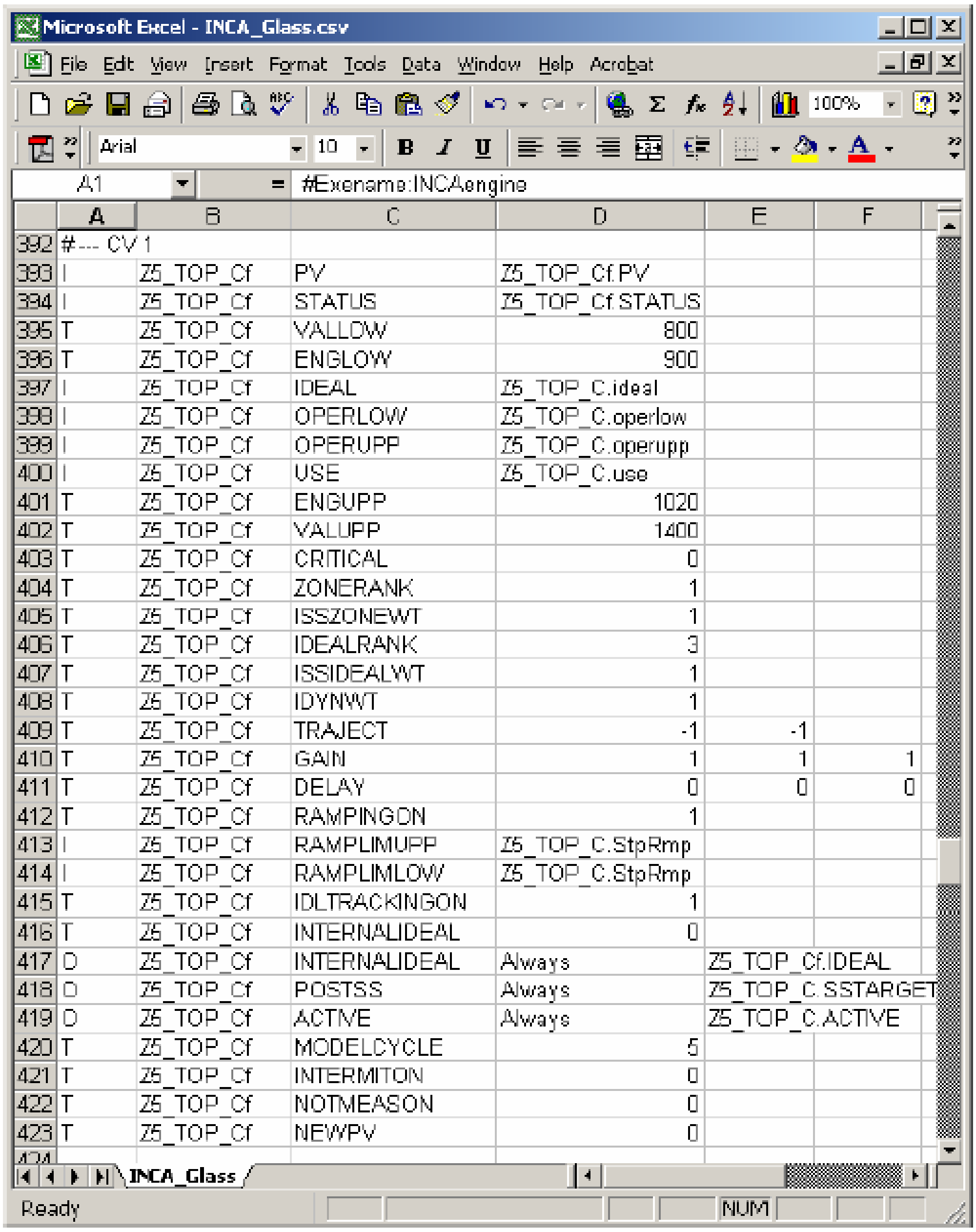


Figure 4-7: Parameters for one CV of an INCA controller in form of an Excel table




| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 392 | #--- CV 1 | | | | | |
| 393 | I | Z5_TOP_Cf | PV | Z5_TOP_Cf.PV | | |
| 394 | I | Z5_TOP_Cf | STATUS | Z5_TOP_Cf.STATUS | | |
| 395 | T | Z5_TOP_Cf | VALLOW | 800 | | |
| 396 | T | Z5_TOP_Cf | ENGLOW | 900 | | |
| 397 | I | Z5_TOP_Cf | IDEAL | Z5_TOP_C.ideal | | |
| 398 | I | Z5_TOP_Cf | OPERLOW | Z5_TOP_C.operlow | | |
| 399 | I | Z5_TOP_Cf | OPERUPP | Z5_TOP_C.operupp | | |
| 400 | I | Z5_TOP_Cf | USE | Z5_TOP_C.use | | |
| 401 | T | Z5_TOP_Cf | ENGUPP | 1020 | | |
| 402 | T | Z5_TOP_Cf | VALUPP | 1400 | | |
| 403 | T | Z5_TOP_Cf | CRITICAL | 0 | | |
| 404 | T | Z5_TOP_Cf | ZONERANK | 1 | | |
| 405 | T | Z5_TOP_Cf | ISSZONEWT | 1 | | |
| 406 | T | Z5_TOP_Cf | IDEALRANK | 3 | | |
| 407 | T | Z5_TOP_Cf | ISSIDEALWT | 1 | | |
| 408 | T | Z5_TOP_Cf | IDYNWT | 1 | | |
| 409 | T | Z5_TOP_Cf | TRAJECT | -1 | -1 | |
| 410 | T | Z5_TOP_Cf | GAIN | 1 | 1 | 1 |
| 411 | T | Z5_TOP_Cf | DELAY | 0 | 0 | 0 |
| 412 | T | Z5_TOP_Cf | RAMPINGON | 1 | | |
| 413 | I | Z5_TOP_Cf | RAMPLIMUPP | Z5_TOP_C.StpRmp | | |
| 414 | I | Z5_TOP_Cf | RAMPLIMLOW | Z5_TOP_C.StpRmp | | |
| 415 | T | Z5_TOP_Cf | IDLTRACKINGON | 1 | | |
| 416 | T | Z5_TOP_Cf | INTERNALIDEAL | 0 | | |
| 417 | O | Z5_TOP_Cf | INTERNALIDEAL | Always | Z5_TOP_Cf.IDEAL | |
| 418 | O | Z5_TOP_Cf | POSTSS | Always | Z5_TOP_C.SSTARGET | |
| 419 | O | Z5_TOP_Cf | ACTIVE | Always | Z5_TOP_C.ACTIVE | |
| 420 | T | Z5_TOP_Cf | MODELCYCLE | 5 | | |
| 421 | T | Z5_TOP_Cf | INTERMITON | 0 | | |
| 422 | T | Z5_TOP_Cf | NOTMEASON | 0 | | |
| 423 | T | Z5_TOP_Cf | NEWPV | 0 | | |
| 424 | | | | | | |

## 4.3 Illustrations for ModPreCon

Figure 4-8: System architecture for DCS-embedded predictive controller ModPreCon

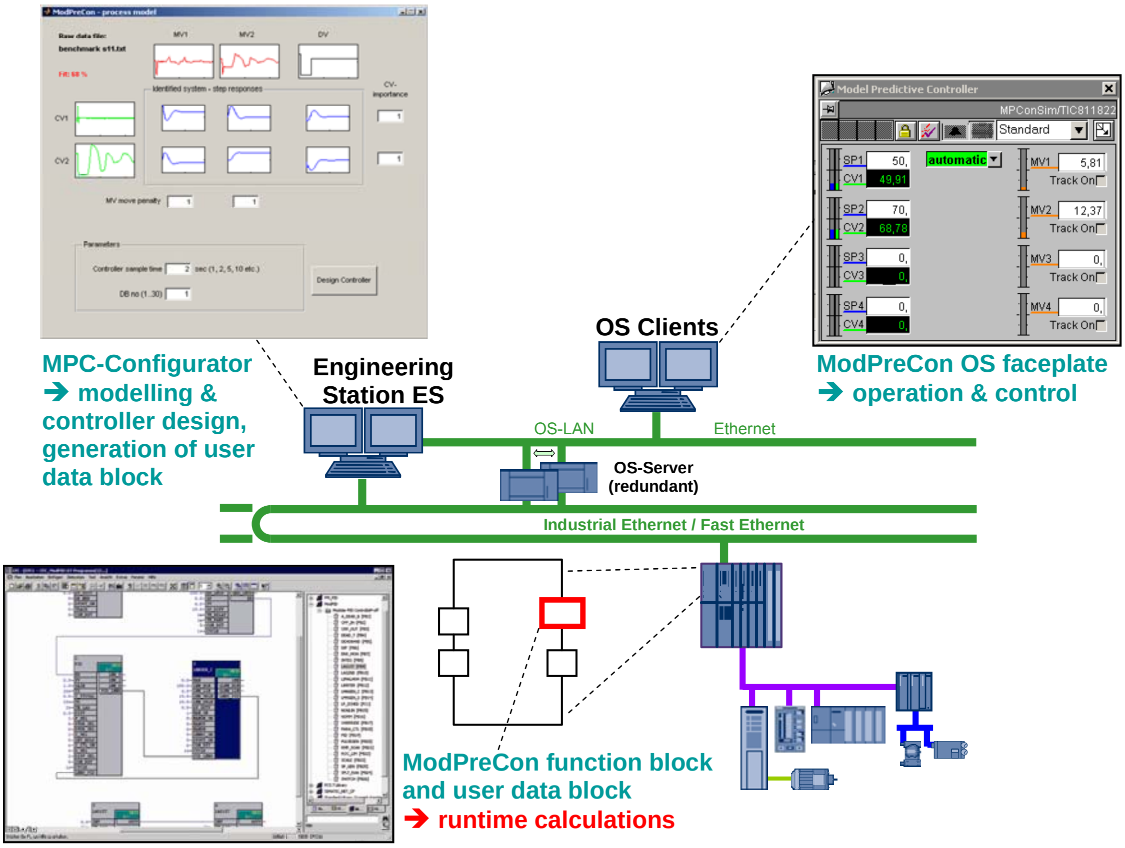


Figure 4-9: Model predictive controller ModPreCon as PCS 7 function block

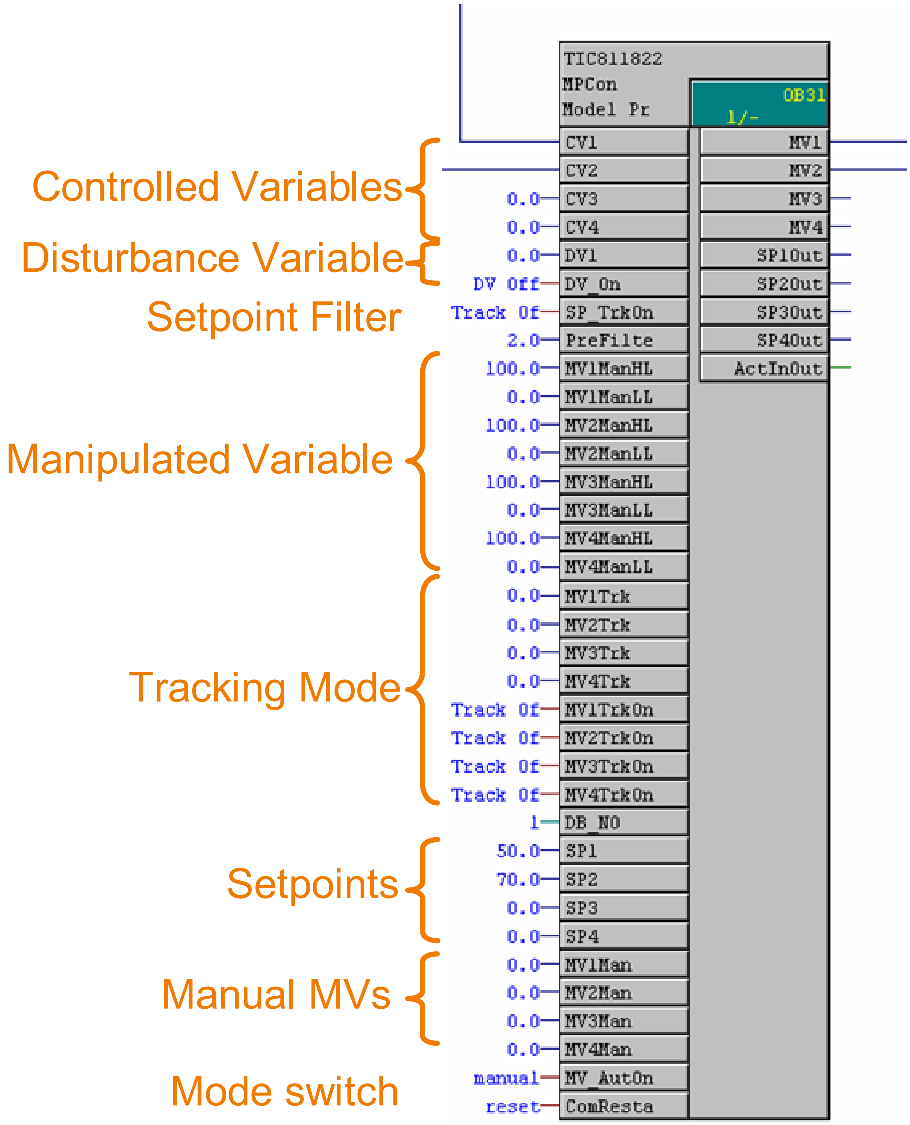


Figure 4-10: ModPreCon faceplate on PCS 7 Operator Station

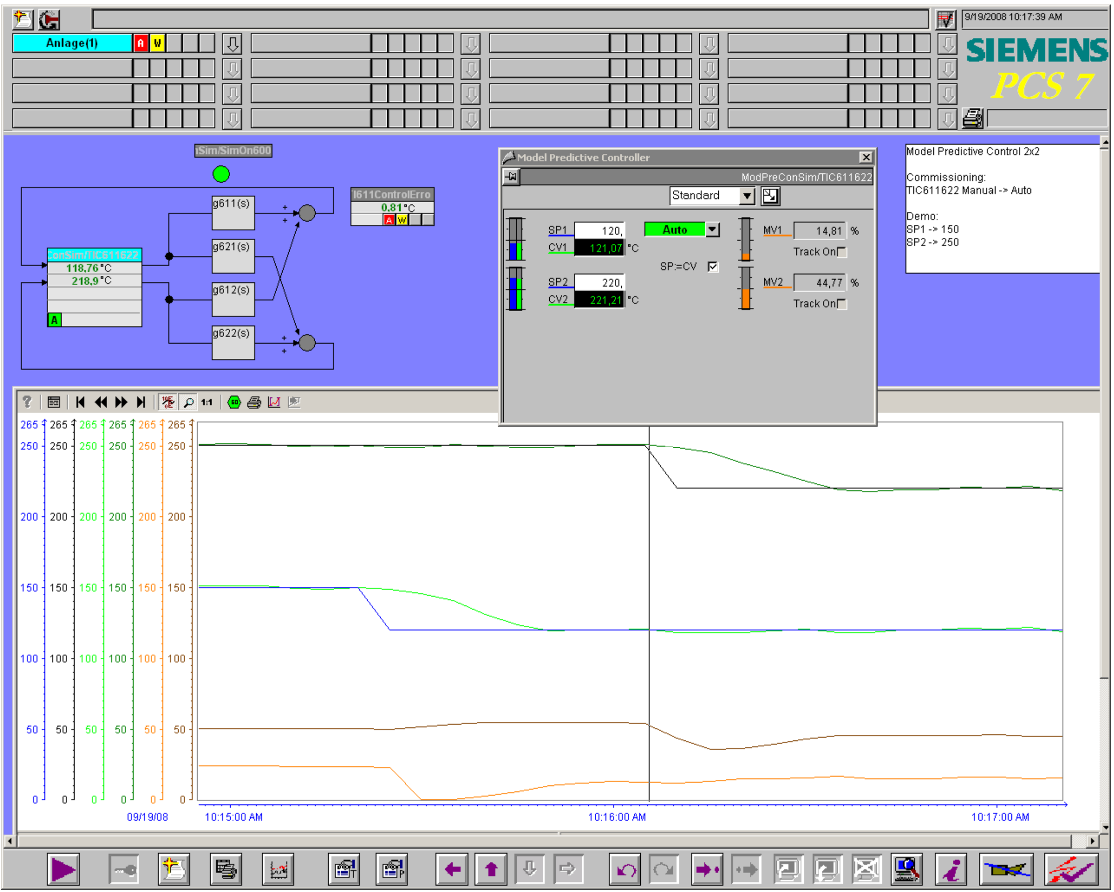
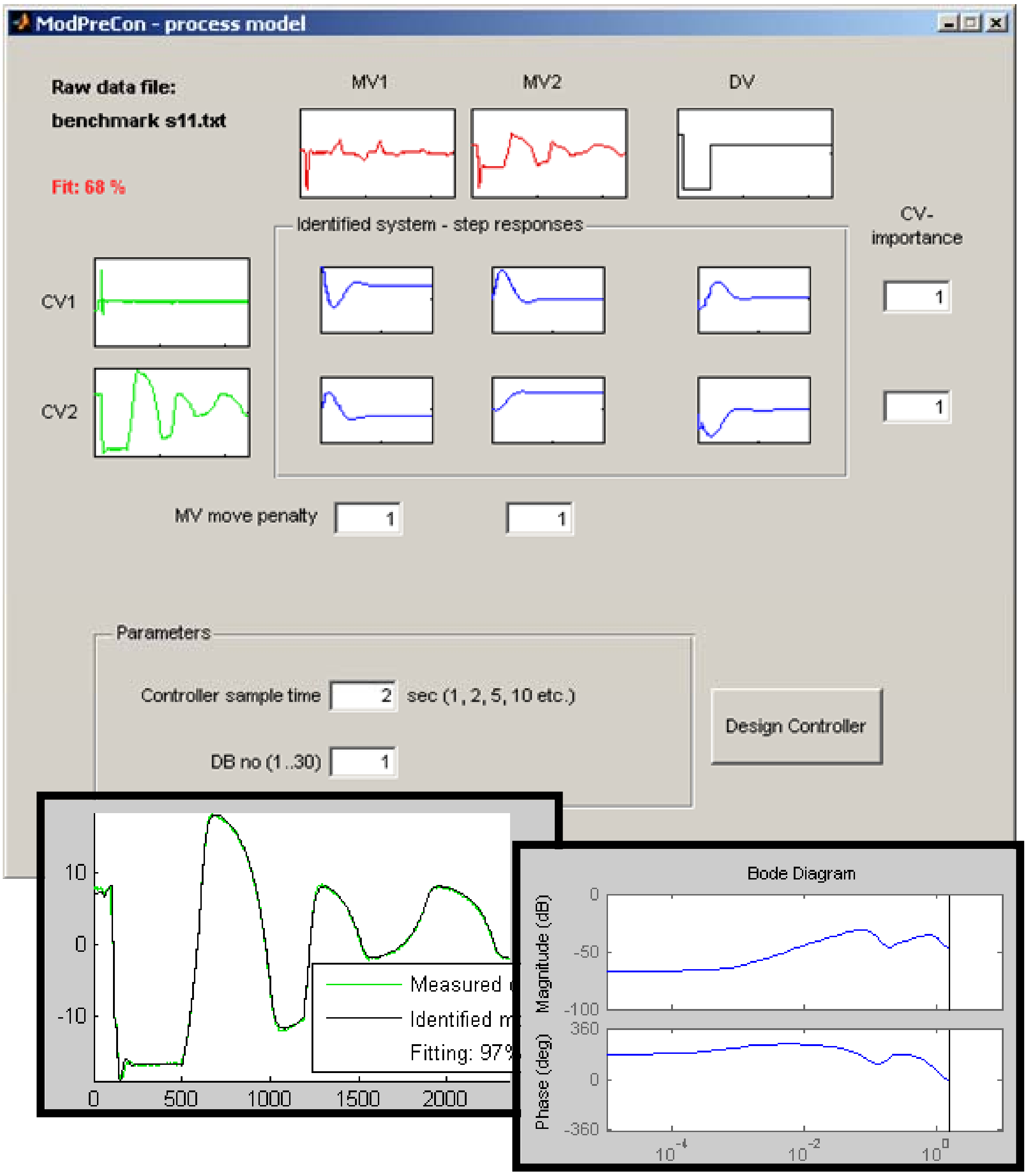


Figure 4-11: GUI of MPC configurator in second working step: display of process model and specification of controller parameters



## 4.4 Hints for Selection of Appropriate Product

### 4.4.1 Arguments for the Application of ModPreCon

- Higher availability of runtime algorithm in automation system, up to exploitation of redundant SIMATIC hardware.
- More easy integration in PCS 7.
- No software license costs.
- Less engineering costs.
- Look&feel of ModPreCon are similar to conventional PID controllers. Therefore you need less time to get familiar with it, and in most cases there is no need to call for external consultants as experts for specialized MPC software packages.
- In general, INCA is a tool „from experts for experts“ (similar to the other add-on products by Ipcos) and requires the appropriate time to get familiar with the software and the theory behind – while the no-charge Siemens tool has advantages with respect to usability.
- Summing up, the starting prize for a turn-key ModPreCon solution is reduced by an order of magnitude compared to an INCA solution. This also means that small and medium-sized applications, that do not allow amortizing a full-blown MPC, become attractive for predictive control.

### 4.4.2 Arguments for the Application of INCA

- For larger MPC applications with more than 4 interacting MVs and CVs the combination of several ModPreCon function blocks with coupling by a disturbance compensation at the “joint” is principally feasible, but INCA will provide better control performance in such cases.
- As a tool „from experts for experts“, INCA offers a lot of features, functions and tuning parameters, and is promising very high performance if applied by professionals.

In the following cases, the application of INCA is strongly recommended, because ModPreCon does not dispose of the required features:

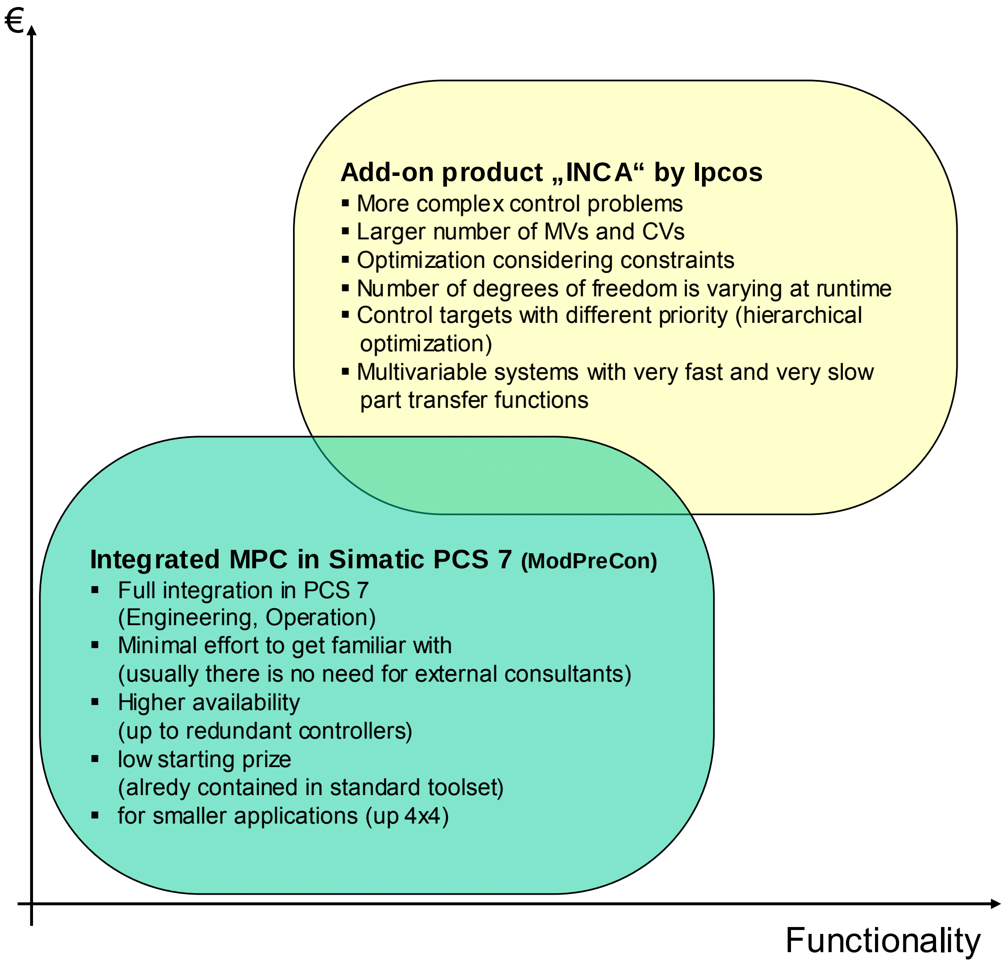
- Larger control problems, where several MVs have to be driven to the constraints in order to achieve optimal performance. Only an online optimization is capable of finding the ideal working point at the intersection of several constraints at runtime.
- Larger control problems, where the number of degrees of freedom is varying frequently at runtime, because CVs or MVs are switched on/off or are hanging at limits. Only an online optimization considering constraints can make sure that the mathematically optimal solution of the constrained problem is really found.

- Control problems with much more MVs than CVs. Only an online optimization can make goal-oriented use of these degrees of freedom, e.g. by targeting economically optimal values for the MVs.
- Control problems with control targets of different priority in a fixed ranking order. Only a hierarchical online optimization can make sure that targets of lower rank are considered only if all targets of higher rank are already fulfilled completely. Example: plant “safety” has higher rank than product quality; product quality has higher rank than reduction of resource consumption. (Remark: the term “safety” in this context refers to staying within limit values, it does not refer to replacing dedicated safety oriented controllers, safety shutdowns etc.)
- Numerically „stiff“ control problems, where inside of a multivariable process, very fast and very slow part transfer functions are interacting. In these cases, dedicated model structures in INCA like e.g. state space models are helpful.

In the meanwhile there are two extensions of INCA, that are not yet listed in the PCS 7 add-on catalogue, but could in principle be interfaced to PCS 7 similar to INCA:

- INCA NL for nonlinear processes like e.g. batch reactors or cristallers. Existing nonlinear physical models are used primarily instead of the experimental identification of linear models from learning data.
- INCA MPC4Batch with special features for batch processes. Model and controller parameters are adapted to the different phase of a batch process. A batch-to-batch observer and controller provide adaption of setpoints and constraints based on measurements of batch end quality. By using existing physical models for heat and energy balances of the reactor the effort required for experimental modeling is reduced considerably. A nonlinear model of the reaction kinetics is deduced from historical batch data.

Figure 4-12: "Functionality has its prize"



# 5 Summary

Some similarities are obvious in all three comparisons.

Advantages of PCS 7 embedded APC products:

- **Availability**: is in general higher on the SIMATIC CPU compared to a Windows PC, moreover the advantages of redundant hardware can be exploited.
- **Costs**: for the PCS 7 embedded APC products, there are no or only small software license fees.
- **Usability**: for the PCS 7 embedded APC products, there is less expert know how required, look&feel are similar to conventional automation functions, the user is guided.
- **Engineering effort**: the PCS 7 embedded APC products are developed to allow for fast and easy engineering and commissioning, the number of parameters to be specified by the user is minimized.

Advantages of Ipcos add-on products:

- **Functionality**: the Ipcos products provide nearly all features that are available from mathematical theory in this context.
- **Performance**: the Ipcos products are state-of-the-art with respect to control performance, approximation precision etc.
- **Flexibility**: a large number of tuning parameters allow adapting the Ipcos products very precisely to specified requirements.
- **Application area**: the high-performance products by Ipcos can be applied even for very large or very difficult applications.

# 6 History

Table 6-1: History

| Version | Datum | Modification |
|---|---|---|
| V1.0 | February 2009 | 1st release |
| | | |