SIMULATION FOR VIRTUAL COMMISSIONING

Reimar Schumann[1], Markus Hoyer[1], Giuliano C. Premier[2]

[1]Hannover University of Applied Sciences and Arts,
Research Center AUBIOS
Ricklinger Stadtweg 120, 30459 Hannover, Germany
[2]University of Glamorgan
Faculty of Advanced Technology
CF37 1DL, Pontypridd, Wales

reimar.schumann@fh-hannover.de (Reimar Schumann)

Abstract

Due to the rising complexity of industrial production plants, the commissioning phase becomes more and more critical with respect to costs and time. In order to avoid costly physical correction measures during real plant commissioning, a virtual commissioning phase may be introduced in the plant engineering workflow after completion of plant engineering and before the plant is built. This paper describes the concept of virtual commissioning for production plants and discusses the realization tasks involved. Different approaches for the realization of virtual commissioning systems are reviewed with respect to modelling and simulation requirements. The efficient generation of simulation models based on the engineering data available from a plant CAE system is discussed in general. A prototype realization demonstrates how a simulation model for virtual commissioning can be generated automatically using plant CAE data. The concept is illustrated at a fresh cheese production plant: it is shown how the virtual commissioning system can be executed in the context of a plant CAE system and how it can be used to check the appropriate positioning of a quality sensor. Finally the actual development state is discussed and future tasks are identified which have to be solved to make virtual commissioning simulation applicable in an industrial engineering environment.

Keywords: Production Processes, Process Control Systems, Virtual Commissioning.

Presenting Author's biography

Reimar Schumann received the Dipl.-Ing. degree in Technical Cybernetics from the University of Stuttgart in 1976, and the PhD degree in Control Engineering from the Technical University Darmstadt in 1982. From 1983 to 1989, he was head of the process control system R&D department at the VDO Measurement and Control company in Hannover. In 1989, he joined the Hannover University of Applied Sciences and Arts as professor for control engineering and process control systems. His current research interests include computer aided control engineering (CACE) and the design of virtual commissioning environments for industrial production processes. As member of the VDI/VDE Society for Measurement and Automatic Control (GMA) he is chairing the German technical committee VDI/VDE GMA FA 6.11 on CACE.

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1 Introduction

The commissioning of a production plant is a complex process during which all parts of the plant are started-up successively. During this procedure design deficits and construction faults are detected which have to be corrected by rebuilding or replacement of the affected plant parts. As industrial plants become more and more complex, these correction measures create increasing time delays and costs during the commissioning phase [1]. The question is how this situation can be bettered.

One possible answer is the introduction of a virtual commissioning phase before the plant is built. Here, the commissioning procedure is carried out at the virtual plant, which is more or less a realistic simulation of the plant with production process and process control system. As design deficits are detected before the plant is built, they can be easily corrected in the design documents avoiding costly and time consuming reconstruction of the real plant. However, the principal question has to be solved how and at which costs such a virtual commissioning procedure can be realized.

This paper will concentrate on the simulation aspects of virtual commissioning and is organized as follows: First, the integration of virtual commissioning in the plant engineering process is discussed in general and the different requirements for plant simulation during plant engineering are reviewed. Then the general set-up of a virtual commissioning simulation is outlined reconsidering various approaches. The generation of simulation models for virtual commissioning is then discussed first in general and then demonstrated with the Model^{CAT} prototype which realizes the automatic generation of a virtual commissioning simulation based on the planning data of a plant CAE system. The conclusions discuss future activities required to make the proposed approach practical.

2 Virtual Commissioning in Plant Engineering

Virtual commissioning should be done after completion of plant engineering and before starting the realization of the plant. This means that in the plant engineering process as depicted in Fig. 1, the virtual commissioning phase should be added directly at the end of detail engineering. At this time virtual commissioning may be carried out based on the complete planning data for production process and process control system which result from the plant engineering process.

Virtual commissioning tests may be done using a variety of approaches: compatibility tests between components and media (e.g. pipe and valve), plausibility tests, checks of piping and electrical wiring and, last but not least and especially for the test of the interaction of process and control functions, dynamic plant simulation.

In virtual commissioning, plant simulation will be used to check the properties of the (chemical) process and its control functions in detail at the simulated virtual plant which should exhibit all properties of the planned real plant in as much detail as possible. This means that the simulation models used for virtual commissioning simulation should predict the properties of devices, components and process apparatus as installed later and should provide as much insight in process and control system details as possible. This requirement is different to most other occasions where simulation is used in the plant engineering process:

- During the conceptual phase, simulation is used to calculate energy and mass balances or to predict the principal behaviour of different control strategies to be applied. For this simulation generic models are used which are parameterised to reflect the postulated requirements rather than the behaviour of the later installed components.
- During the commissioning phase, the tuning of control functions is often done using online process identification for determination of dynamic process models which are then applied for simulation and optimisation of the control schemes. The identified black block models reflect only local behaviour of the process as seen through the process I/Os of the

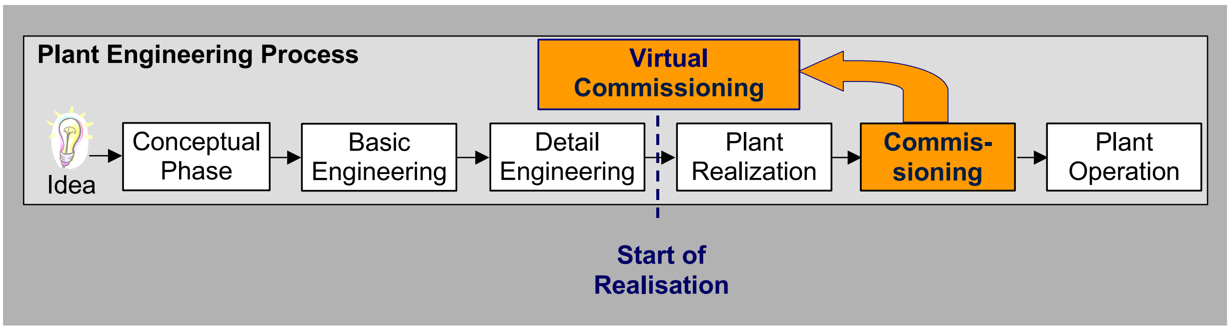

Fig. 1 Virtual Commissioning – a new element in the plant engineering workflow

process control system which is sufficient for the tuning of process control systems but does not provide any insight into the internal behaviour of the process.

- During plant operation (and often already during commissioning), simulation systems are used to train plant operators with respect to process and control operation allowing the necessary insight into process and control system. The process models in such operator training systems have to reflect the real process behaviour with all installed devices and components, a similar requirement as for virtual commissioning simulation.

3 Realization of Virtual Commissioning

The virtual commissioning simulation (VCS) environment should reflect the general structure of a plant which is subdivided in the (chemical) production process and the process control system (PCS). This means, simulation should be separated in a process simulation and a PCS simulation. In addition, the VCS system must contain a specific operator interface which should allow the analysis of process and control system behaviour in as much detail as possible. In literature several approaches can be found with respect to the realisation of VCS in the context of plant engineering.

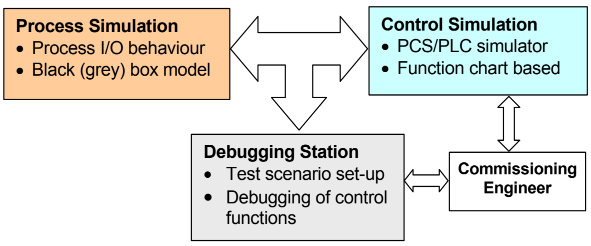

Fig. 2 Special VCS for debugging of control functions

One group of approaches is focussed on the virtual commissioning of the control functions alone, see e.g. [2]. The general set-up of such a system is shown in Fig. 2. The process simulation must reflect only the process behaviour at the process I/Os as required to analyse the behaviour of the process control system. This means that a black box process simulation is sufficient for such a VCS. The control simulation is done by simulating the functions of the PLC or of the complete PCS. In the latter case the control simulation may comprise an operator interface by which the commissioning engineer is able to access process data in the same way as the operator during process operation. However, for the debugging of the process control functions an additional user interface – here called debugging station - must be provided allowing the set-up of test scenarios and intensive tests of the control functions with deeper insight into the programmed control functions. Typical examples for such systems are SIMIT [3] or WinMOD [4]. The process models are generated manually based on libraries, for control simulation the original software is executed on emulated PLC or PCS. Due to this set-up no or only very restricted insight into the process behaviour is provided, nevertheless, this is sufficient for the debugging of the control functions.

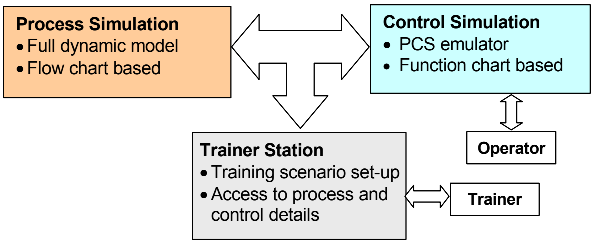

Fig. 3 General structure of OTS system

An alternative approach for the realization of VCS systems are operator training simulation (OTS) systems, see Fig 3. These systems consist of a full dynamic process simulation which are mostly flow chart based to allow easy access to process details, and a control simulation which is normally done using the original PCS software on a PCS emulator. The operator to be trained uses the normal PCS interface to access and operate the process through the standard operation screens. Through a special trainer interface, the trainer can set-up training scenarios and has access to all required process and control system details of the simulation. Detailed descriptions of the set-up and use of OTS systems can be found in [5] or [6]. Bayer Technology Systems (BTS) describe variants for the efficient and cost effective set-up of OTS in [7], and according to BTS the costs for the realization of an OTS are estimated to range between 0.5 and 1 % of the overall plant investment. Successful application of an OTS system to virtual commissioning has been reported already in 2001 by ABB [8]. Nevertheless, it should be noted that the main requirement for the use of an OTS for virtual commissioning is the fast availability of simulation after the end of plant engineering. This may be accomplished for the control simulation by the use of the original PCS software on an emulated PCS, but for the process simulation the efficient and fast generation of the process model represents still the main obstacle. In addition, the trainer station interface must be adapted to satisfy the requirements of a VCS.

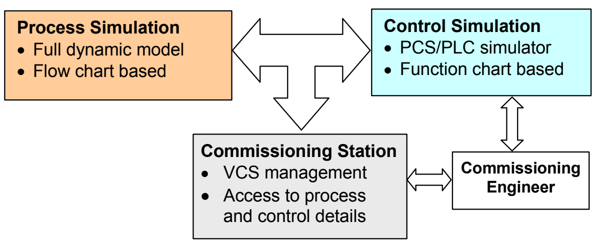

Fig. 4 General structure of VCS system

The general full structure of a VCS system is shown in Fig. 4. The structure is very similar to the structure of an OTS. For the process simulation standard simulators like HYSIS or D-Spice may be used, control simulation may be arranged using the original PCS software on a PCS emulator. In contrast to the OTS, in the VCS system only one person, the commissioning engineer must be provided with full control over the PCS operator interface and over the commissioning station by which different VCS scenarios may be set-up and also details of the process and control simulation may be accessed which are not accessible through the normal PCS operator interface.

The main challenge for the realization of VCS is the fast and efficient provision of process models which reflect the expected behaviour of the real plant sufficiently with respect to the required simulation accuracy and detailing down to the component and device level. In [5] it is mentioned that OTS models may be the final version of a "life-cycle simulation" by which the simulation requirements of all life-cycle phases may be fulfilled by one simulation tool. Nevertheless, as a VCS must reflect the behaviour of the real process rather than the requirements defined in the early engineering phases, the simulation model for VCS should be aggregated from the simulation models of components and devices as built into the plant and should not be derived from the requirements by parameterisation of generic models.

4 Generating Simulation Models for Virtual Commissioning

From the discussion above, it is obvious that the simulation models required for virtual commissioning should reflect the properties of the later installed process and its control system as realistically as possible. Furthermore, it should be possible to access simulation details down to component and device level which means that the simulation should be aggregated from component models reflecting the real behaviour of the physical devices. The majority of such component models could be provided by the component manufacturers, and such component models will exhibit only the limited degrees of freedom which the real devices have.

When setting up a simulation for virtual commissioning efficiently, the task is to aggregate the simulation model largely from standard component models in industrial catalogues (to be provided by the manufacturers) and to add only special simulation models of more complex modules like reactors, distillation columns etc. using the process expertise of process designers and simulation experts. The model aggregation must be done based on the process and control structure which is the result of the engineering process and available at the end of detail engineering.

Assuming that this structural information is contained in the database of a plant CAE system together with

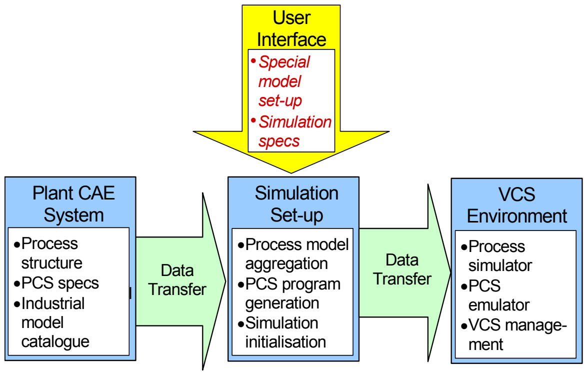

Fig. 5 General scheme for VCS simulation model generation

an industrial catalogue of component simulation models, an almost automatic procedure may be conceived for generating the plant simulation model for virtual commissioning as shown in Fig. 5: The structural information about process and PCS may be extracted from the database of the plant CAE system automatically and should be used to organize the structure of the simulation models for process and PCS. The simulation models of the standard components may be directly retrieved from the industrial model catalogue and automatically parameterised according to the specifications in the CAE database. Only such special simulation models which are not contained in the industrial catalogue have to be added individually – using special model catalogues of the process designers or generic models which have to be parameterised according to the specifications or otherwise. Also some simulation parameters will still have to be specified manually by the user. Theoretically it should be possible to realize such a semi-automatic scheme based on the CAE system database as the plant specifications stored there are sufficient to build the plant physically provided that the required plant parts and components are available - and should therefore be sufficient to build the virtual plant, i.e. the simulation model of the plant provided that the virtual parts, i.e. the simulation models of the components, are available.

The realization of such an approach, however, requires the solution of a number of tasks, including

- organisation of an industrial model catalogue,
- realization of the simulation set-up procedure including
  - retrieval of information from the CAE database
  - aggregation of simulation models
  - compilation to simulation scripts and PCS configuration
  - design of a user interface
- organisation of the VCS environment with

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- selection of process simulator and PCS emulator,
- synchronisation of process and PCS simulation and
- design of the VCS management.

To show the feasibility of such an approach the Model^{CAT} prototype was devised with a basic solution for all tasks.

5 Model^{CAT} Prototype

The Model^{CAT} prototype [9] demonstrates the set-up of an automatic plant model aggregation based on the information collected in the database of a plant CAE system at the end of detail engineering. The starting point of the concept is the database of the plant CAE system Comos [10] in which all design information of the plant is stored as required for building the plant, see Fig. 6. The component database of Comos was extended with a model catalogue for all required component simulation models. In the Model^{CAT} prototype, the VCS environment is organized based on Matlab/Simulink [11] for the PCS part and gProms [12] for the process part which is not ideal with respect to the general requirements listed above but this configuration was readily available at the time of design and sufficient to show the principles. So the control functions were not realized using a PCS emulator but by a general control simulation with Simulink and the process part was realized with a text based gProms version which can be run embedded in Simulink using the standard gO:Simulink interface.

The main design emphasis was laid on the automatic generation of the simulation models required for Simulink and gProms. For this purpose the software module MAM (Model Aggregation Module) was realised which organizes the complete automatic model aggregation procedure including

- selection of the plant part to be simulated in the Comos P&I diagram,
- detection of components and interconnections to be simulated,
- retrieval of component data from the Comos database including simulation models,
- aggregation of process and control simulation models and
- compilation to Simulink and gProms scripts.

To support the commissioning engineer during set-up of the virtual commissioning simulation, a smart graphical user interface (GUI) was specified and realized which organizes the interaction of user, CAE system, MAM and VCS environment. The main tasks of the GUI are

- graphical specification of the plant part in the Comos P&I diagram,
- interactive and guided specification of boundary and initial values,
- specification of simulation parameters and
- definition of graphical output.

The commissioning station management was restricted to automatic start-up of Simulink and gProms, transfer of simulation scripts from MAM and graphical presentation of simulation results.

6 Application Example: Fresh Cheese Production Plant

An existing industrial fresh cheese production plant was chosen to highlight the use of Model^{CAT} for the automatic set-up of a VCS environment. The process scheme of the fresh cheese production plant is shown in Figure 7.

The engineering data for this plant are stored in the plant CAE system Comos together with the component simulation models required for simulation of the plant. The central part in the process is the separator which splits up the curd (thick milk) stream into fresh cheese and sour whey. By efficient control of the separator, it is possible to produce fresh cheese with the required dry matter and protein content using a minimum of milk. For this purpose a NIR (Near Infrared) inline sensor is used to measure the quality parameters dry matter and protein content of the produced fresh cheese.

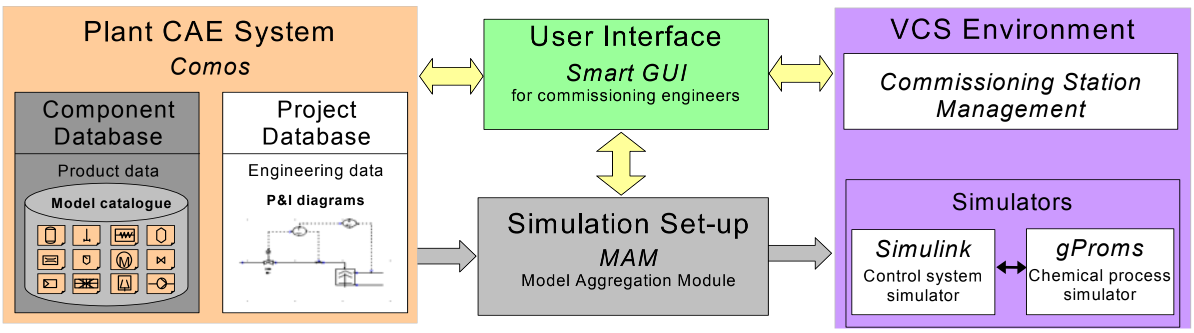

Fig. 6 Schematic overview on Model^{CAT} functions

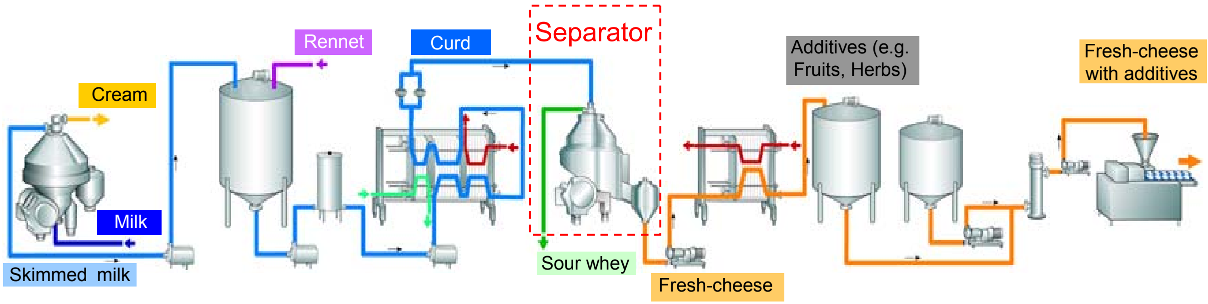

Fig. 7 Fresh cheese production plant

During plant engineering the NIR sensor must be positioned in the production line. The scenario may now be set up as follows: Due to space problems process engineers propose to install the sensor after the first heat exchanger following the separator whereas control engineers prefer a sensor position directly at the fresh cheese outlet of the separator due to the expected control dynamics. To decide about the appropriate positioning a VCS simulation should be done for both alternatives comparing the control performance with respect to the rejection of a partial nozzle blocking as typical separator disturbance.

After completion of plant engineering the actual planning results can be shown in the P&I diagram, Fig. 8. Here the NIR inline sensor QC Q001 is positioned directly after the separator. The separator environment with its instrumentation for the curd input flow control and the cascaded dry matter control should now be simulated for the actual NIR sensor position and also for the alternative position after the heat exchanger.

Using the extended Comos user interface the automatic model aggregation process is started: First the plant area to be simulated is selected by drawing a red rectangle. After a user dialogue defining boundary conditions and simulation parameters, Model^{CAT} generates the corresponding Simulink scheme shown in Fig. 9.

This scheme contains not only the gProms process model block of the separator with control valve and sensors but also the control scheme with the curd flow controller and the cascaded dry matter (DM) controller.

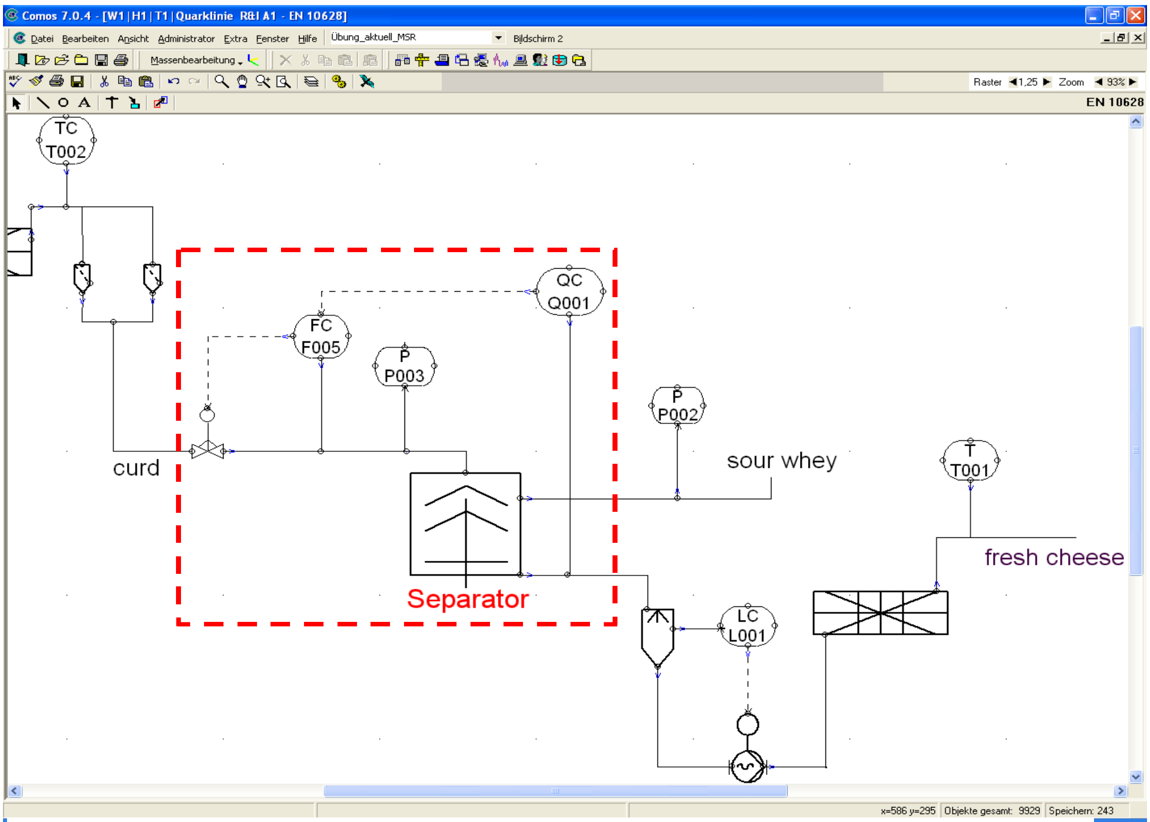

Fig. 8 P&I diagram fresh cheese production

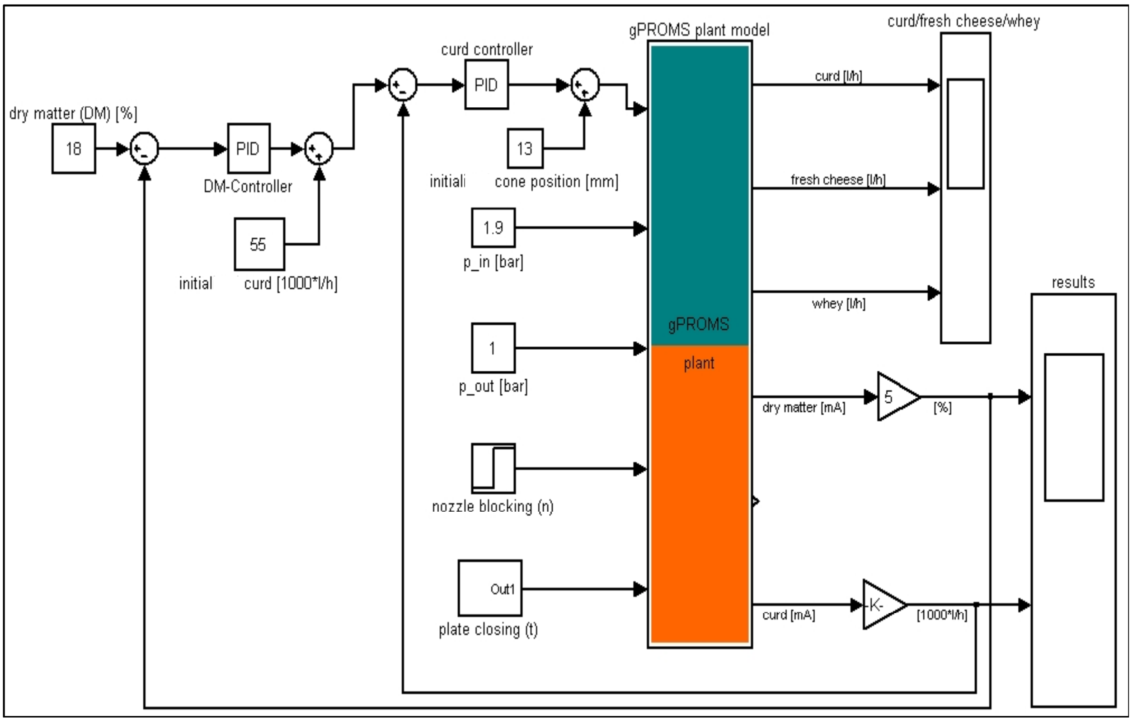

Fig. 9 Simulation scheme for separator with curd flow and cascaded dry matter controller

In case that the dry matter sensor is positioned after the heat exchanger the gProms model block does also contain the heat exchanger model which causes an additional time delay. The control performance of the two sensor positions can now directly be compared by simulation of the Simulink/gProms schemes generated from the two associated different P&I diagrams.

From the simulation results shown in Fig. 10, it becomes obvious that the positioning of the dry matter inline sensor directly at the separator leads to much better control performance compared to the position after the heat exchanger. In the latter case, the additional time delay does allow only small controller gains resulting in inefficient disturbance rejection. From these virtual commissioning simulations with Model^{CAT}, it becomes obvious where the inline sensor should be positioned: directly after the separator. And this result can be easily integrated in the plant engineering data before the plant is built.

7 Conclusions

The Model^{CAT} prototype has demonstrated that it is possible to organize an almost automatic VCS set-up from the planning data in a plant CAE system. However, this had to be made possible by special add-on software modules for the plant CAE system to extend the capabilities of the Comos user interface, to retrieve plant structure and model data from the CAE database and to aggregate the simulation model automatically.

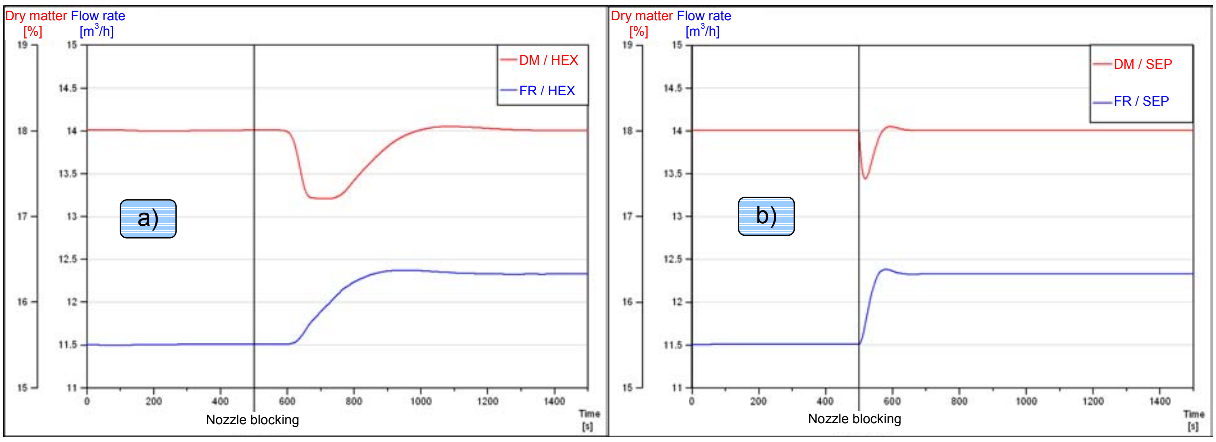

Fig. 10 Model^{CAT} VCS simulation results for separator: nozzle blocking disturbance rejection by control with a) NIR sensor after heat exchanger b) NIR sensor at separator

Also, for the VCS a simple co-simulation of gProms and Simulink was utilized which by no means is optimal with respect to the general VCS requirements.

To make this approach applicable in industry in general a number of tasks has to be solved professionally in the future:

1) Simulation Model Catalogue: A catalogue of simulation models for industrial plant components must be systematically organised and collected such that it becomes available for an automatic model aggregation procedure.

2) Standard Export Interfaces: Plant CAE systems should offer standard data interfaces for the export of plant structure and model data. For the control part, CAEX is already available [13], for the process part this is still a question to be discussed.

3) PCS Emulation: Simulation of the control functions can be done using the original PCS software on a PCS emulator. Ideally, the PCS software should be directly available from the plant CAE system, in practice the PCS software is generated on and available from a separate PCS engineering station.

4) Process Simulation: The process model should be preferably aggregated automatically from the process structure and simulation models in the model catalogue, only special models should be added manually. It is desirable to use in the model catalogue a tool independent modelling language like Modelica [14]. Process simulation of process functions may be done using a standard process simulation tool. This should provide a standardized interface for the import of simulation models and should allow scalable access to the simulation models on different detailing levels.

5) VCS Management: VCS must be organized and managed using an additional management user interface. The features of the VCS management must be further elaborated and should comprise start-up and management of cooperative simulation of process and PCS, the set-up of test scenarios and organized access to simulation details.

Even the simple application example with Model^{CAT} has demonstrated the usefulness of a VCS: Design deficits are detectable from simulation results and can easily be corrected in the planning data. Provided that the tasks listed above can solved – the most difficult part is probably the systematic collection of component models for the model catalogue - VCS should become an essential new component in the plant engineering workflow which opens the path for efficient cost reduction of real commissioning. Using VCS not only the plant engineering data may be checked and corrected: In addition the VCS plant model can be used for optimisation of the process structure in general, for operator training and, last but not least, as base for the application of computer aided control engineering (CACE) tools to tune and optimise standard and advanced control functions.

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