PROCESS SIMULATION FOR CHEMICAL AND PETROCHEMICAL PLANTS

Incorporating Process Simulation into Control Engineering

Definition of Control System in Chemical and Petrochemical Plants requires specific know-how with the target to optimize and improve existing systems and design new ones. When designing a system, it is necessary to follow some basic steps like modelling the system, analyse such model, design the system/controller and finally, implement it and test it. In order to bridge the gap between the strong and deep knowledge about classical control techniques and the new process simulation features, Inprocess proposes a simulation-based course, targeting process control engineers, where the right combination of theory and practical exercises is fulfilling such professional needs. Training could be extended to Multivariable model predictive control (MPC) topics.

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Control engineering is the engineering discipline that focuses on the modelling of a diverse range of dynamic systems and the design of controllers that will cause these systems to behave in the desired manner. Although control engineering has diversified applications that include science, finance management, and even human behaviour, our intention is to focus on its utilization in **Chemical Engineering** as applied to the processing industries. The field of control within Chemical Engineering is often known as **Process Control**. It deals primarily with the control of variables in a petrochemical/chemical process in a plant.

Looking back at the control engineering history, chemical engineers were slow in adapting the benefits of existing control literature (developed originally for other systems like amplifiers, servomechanisms or mechanical systems) to the design of process control schemes applied to the hydrocarbon and chemical processing industries. Initially maybe due to the unfamiliar terminology, but there was also the basic difference between chemical processes and mechanical or pneumatical systems which provoked this postponement of process control theory and its industrial implementation. Hydrocarbon and chemical processes are intended to operate normally at a constant setpoint, and process disturbances impacts are minimized by the presence of large-capacity elements. Opposite, such elements would tend to slow the response when controlling mechanical systems. Similarly, the effect of time delay or transport lag is one of the major factors in process control but it is rarely considered in references dealing with mechanical systems. In the processing industries control systems, the presence of interacting first-order elements and distributed disturbances is much higher than the second-order elements present in the control of mechanical and electrical systems. The described differences made many of the examples of design of control of servomechanisms of little use to those chemical engineers interested in controlling the processes in the chemical and hydrocarbon industries [1].

Incorporare la simulazione di processo nell'ingegnerizzazione del controllo

Definire sistemi di controllo di impianti chimici richiede un know-how molto particolare, teorico ed operativo, allo scopo di analizzare e migliorare i sistemi esistenti e progettarne nuovi per soddisfare esigenze specifiche. Nella progettazione di un sistema, è necessario seguire alcuni passi fondamentali come modellazione del sistema, analizzare tale modello, progettare il sistema di controllo e infine, attuare e verificare il controllo implementato. Al fine di colmare il divario tra la conoscenza classica delle tecniche di controllo e la moderna simulazione, Inprocess propone dei corsi, alternando teoria ed esercizi pratici per coprire le diverse esigenze professionali e colmare eventuali lacune del personale di ingegneria o operativo. I corsi possono estendersi al Controllo Predittivo Multivariabile (MPC).

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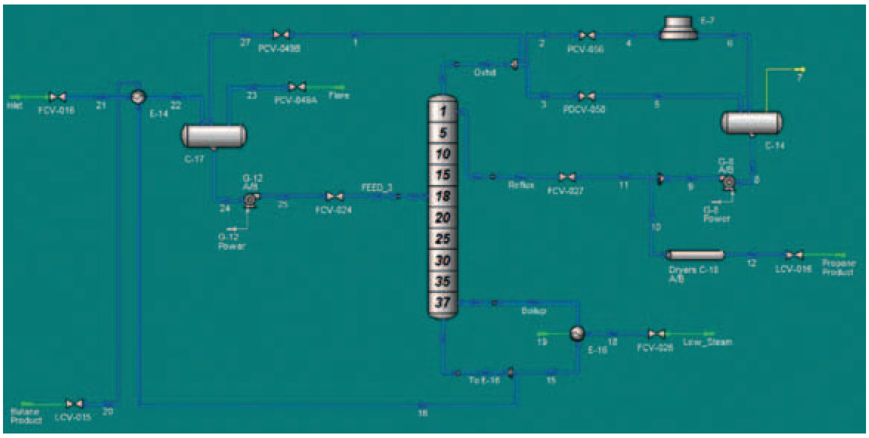

Figure 1 - Example of a Process Simulator model ready to run in dynamics mode

Control engineers working in a processing plant can have different origins, backgrounds and strengths. It is their job to analyse and improve existing systems, and to design new systems to meet specific needs. When designing a system, or implementing a controller to augment an existing system, it is necessary to follow some basic steps like modelling the system, analyse such model, design the system/controller and finally, implement and test the controller. For decades, the first two steps have been based on using transfer functions, frequency-domain analysis, and Laplace transform mathematics. For single control loops lineal systems - like those from the electromechanical areas from which these classical control techniques emerged - this approach is well suited. As an approach to the control of hydrocarbon and chemical processes, which are often characterized by multi-loop, nonlinear systems and large doses of dead time, such classical control techniques have some limitations.

Process Simulation

The key benefits of process simulation are related to the improved process understanding that it provides. By understanding the process more fully, several benefits follow naturally. These include enhanced profitability, safer designs, improvements in control system design, improvements in the basic operation of the plant, and improvements in training for both operators and engineers **[2]**. Using a first-principles dynamic model, control philosophies can be designed, tested, and even tuned prior to start up (see ►**Figure 1** for a dynamic simulation model example). Using adequate data connectivity protocols (like OLE for Process Control, OPC) rigorous dynamic models are nowadays even used to checkout **distributed control systems** (DCS) or other standard control systems configurations. All of these features make dynamic simulation ideally suited to control applications.
However, process control systems design is, unfortunately, still often left until the end of the plant design cycle. This practice frequently requires to elaborate a control strategy in order to make the best of a poor design. Dynamic process simulation, when involved early in the design phase, can help to identify the important operability and control issues and influence the design accordingly. Clearly, the ideal is not just to develop a working control strategy, but also to design a plant that is inherently easy to control.
With current availability of powerful computers and dynamic simulators, it is possible to approach process control system design, which involves the fast solution of sets of differential equations without the need to move to the non-intuitive frequency-domain mathematics but remaining in the time-domain to solve the differential and algebraic equations together. In this way, engineers and operators are capable of realizing about the interactions between the process, the control system and the load variables in a virtual environment, identical to the one in the real plant. Traditional boundaries between process engineering and plant operations are dissolving as the ability to simultaneously analyze simulation and plant data expands **[3]**.

Bridging the Gap with a Process Simulation for Control Engineers Hands-On Course [4]

Simulation for Advanced Classical Control

In order to bridge the gap between the strong and deep knowledge about classical control techniques of nowadays control professionals and the time-domain analysis that dynamic (and even steady-state) process simulation is providing in real-time, Inprocess proposes a hands-on simulation course, where the right combination of theory and practical exercises is fulfilling such professional needs. To match course length with usual availability for self-training of industry professionals, the content of the sessions has been spread along twenty-five hours (three working days)
The initial course lessons are focused on breaking the barriers that a new user might have with a commercial process simulator. Getting used to the GUI and the basic steps needed to build a simple steady state case of a real distillation column, are followed as course introduction
The column steady state model is subjected to a sensitivity analysis of the dependent vs. independent variables, exporting the results to an external spreadsheet to calculate the steady state gains and the process non-linearity, in the way ►**Figure 2** shows. Still in Steady State, another sensitivity analysis allows students to create a regressed equation to relate product quality as a function of column pressures and temperatures.
Students that by then feel comfortable with a Steady State model of the process learn how to transition it to its Dynamic version, by incorporating the process information that is irrelevant for a steady state solution, like equipment dimensions, equipment heights, and piping equivalent lengths. Final control elements (control valves and alike) are as well included, together with some variable monitoring means (strip charts). Such an open-loop version of the plant is step tested for mathematical robustness and for variable response monitoring prior to control loop "installation" for automatic mass-energy balance regulation by using basic PID and split range controllers. Some basic rules of PID tuning are introduced and tested in the model.

On-Off control, cascade control, ratio control and override logic are successively implemented in some model loops and checked with students. Loops configuration, performance impact and process added value are as well analysed. Feed-Forward concept is explained and implemented in reboiler duty control in order to anticipate column load changes, like training material in ► **Figure 3** details.

The validity of the implemented control strategy to reject disturbances is checked in front of the changes in process variables created by a transfer function block. Noise is also generated with the help of a transfer function. Students also learn how to incorporate simple equipment and instrumentation malfunctions like valve stiction or heat losses into the simulation model.

How to incorporate to the model complex automated control sequences that can be part of a control philosophy is by using the Event Scheduler tool, like a sequence of automatic steps for MVs-FFs.

As three-day course closure, attendees learn how to extract data generated by the simulation model in order to be used by third-party off-line analysis tools, as well as how to import historical process data and how to use them as boundary condition or controller set-point in a dynamic simulation. Students do also compare the performance of two alternative control layouts by duplicating the exiting simulation case and just modifying the control settings in the copied model.

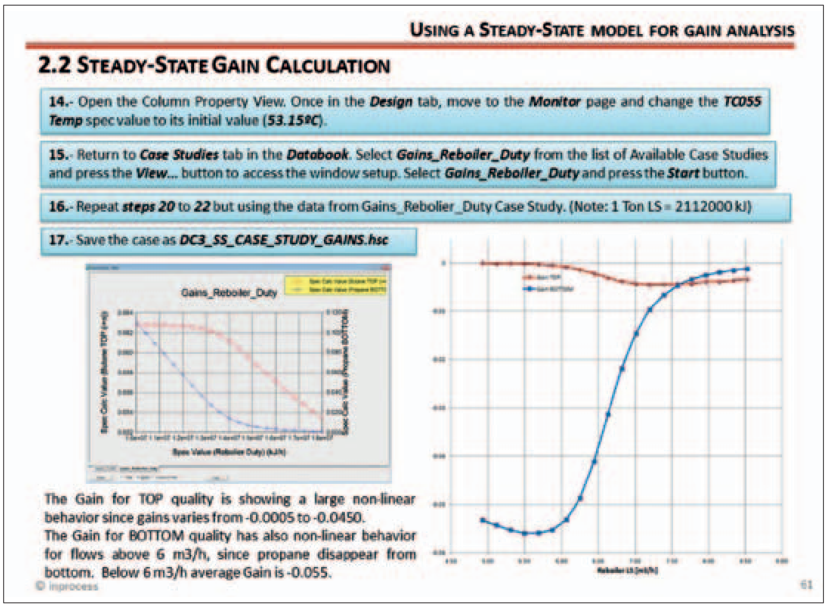

Figure 2 - Example of the Training Material describing the necessary steps to determine the SS Gains

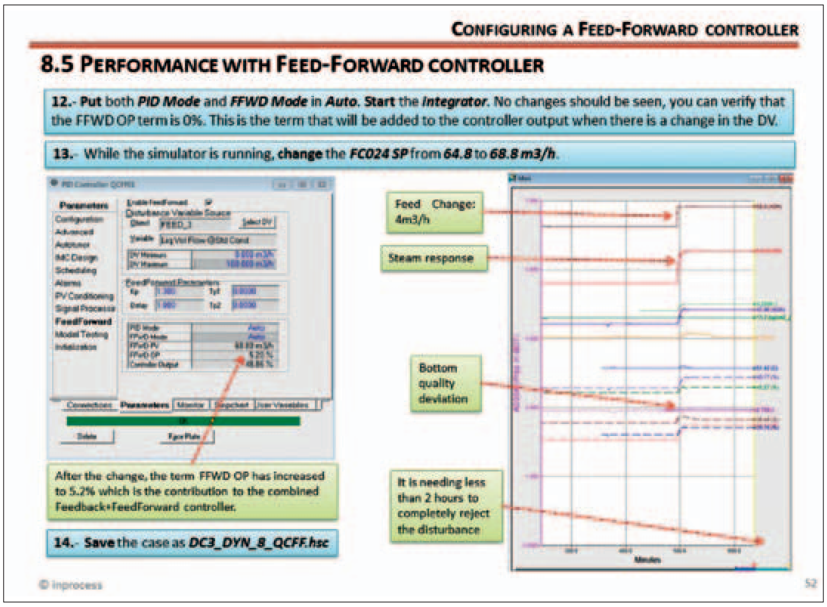

Figure 3 - Example of training material showing how to take advantage of a Feed-Forward controller performance

Simulation for Multivariable Control

Multivariable model predictive control (MPC) topics are not covered in the initial three day courses. If necessary, course content can be extended to see how MPC controllers can provide a superior control, either using the basic MPC implementation offered by the dynamic process simulator or by using a commercially available MPC. For this last case, the controller is configured by step testing the column dynamic model and exporting the generated results to the MPC identification package. Once configured, the MPC is used to control the column, with the same user interfaces than the ones in real control rooms.

Other uses of Simulation for Process Control

In the extended course coverage, additional use of process Simulation for Process Control is shown in exercises where **Relative Gain Array** (RGA) techniques are used; where anti-surge control of centrifugal compressors is configured; where a **Smith-Predictor** or (SISO MPC) controller is implemented for large dead-time processes; where **OLE for Process Control** (OPC) is used as communication protocol to control the dynamic model with an external control algorithm developed in MatLab; and where key control variables are optimized with a SQP algorithm in the steady state simulation model.

References

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[2] Dissinger, Glenn. "Studying Simulation". *Hydrocarbon Engineering*, May 2008.

[3] McMahon, Terry. "Process Simulation and Process Control". *Chemical Engineering Progress*, American Institute of Chemical Engineers, p. 19, September 2013.

[4] *Courses and Events*. Inprocess. 30 November 2016. http://www.inprocessgroup.com/en/news/.