Proceedings
of the 4th International Modelica Conference,
Hamburg, March 7-8, 2005,
Gerhard Schmitz (editor)

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pp. 579-583

Paper presented at the 4th International Modelica Conference, March 7-8, 2005,
Hamburg University of Technology, Hamburg-Harburg, Germany,
organized by The Modelica Association and the Department of Thermodynamics, Hamburg University of Technology

Using Modelica and Control Systems for Real-time Simulations in the Pulp & Paper industry

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Abstract

Metso Paper regularly uses process simulations when designing and delivering a new pulp mill. The simulations have two main purposes. Operators are trained in running the new process before it exists and complex control logic can be validated efficiently before start-up. The simulations are built using Dymola/Modelica, executed in real-time and connected to the plant's control system.

This paper will discuss the general technical solution for using Dymola/Modelica in combination with a control system for real-time simulations. The paper will also provide an overview of the different applications that Metso Paper has implemented. Expectations of future development of Modelica and connected software will be discussed from an industry perspective.

Keywords: dynamic simulation; control system; pulp and paper; operator training; logic verification

1 Introduction

Different kinds of simulations are used within Metso Paper for designing and developing the pulp and paper processes. Static simulations for balancing and dimensioning the process with respect to flows, steam, chemicals etc. The second type is advanced and computational demanding FEM-type of simulations for more detailed simulations and analyses of different optional machine designs. The third type of simulations is the real-time dynamic process simulator for operator training and control system verification. This paper will focus on the real-time dynamic process simulations. A training session using simulators is shown in Figure 1.

Figure 1. Simulator training in progress

When delivering a new machine, process area or a complete mill Metso Paper has offered dynamic process simulations since beginning of the 1990's. The main purpose of these simulations is to train operators and other mill personnel in running the new equipment in an efficient and optimal way. The operators get used to the new operator displays, interlocking logic and most importantly new process dynamics. Difficult and rare process conditions can be introduced in the simulations. By regularly exposing the mill personnel to these difficult situations in the simulator environment, expensive and unwanted stops in the real production can be avoided.

Earlier these types of simulations were made in a single PC where the process simulations as well as a mimic of the real operator displays and the plant's control system was configured. Even if this system worked fine technically speaking and served its purpose as an educational tool, it had some drawbacks. The two major problems with this solution were:

- It was a very expensive solution due to the many engineering hours needed in order to convert the real operator displays and control logic into the simulator world. When new revisions of displays and control logic were made, new revisions must be made in the simulator as well. On top of this, it was very difficult to reuse models and configurations between projects.

- It was difficult to keep the simulator up to date once delivered to a customer since every change in the real control system and operator displays must be followed by a corresponding change in the simulator system. Typically, the changes in the real process were done by the mill personnel while changes in the simulator demanded involvement from other competencies. In practice the simulator and real world configurations slowly drifted apart.

Starting in beginning of year 2001 a new architecture for dynamic process simulations within Metso Paper were developed using Modelica and Dymola. The main difference between the old and new architecture is that in the new architecture the real control system and real operator displays are used instead of including a mimic version of the two into the simulator. The simulation models are also designed in a way that modular building blocks of typical process equipment and areas easily can be reused from project to project. The advantages of the new architecture are substantial

- Since no mimic is done of the operator displays and control logic the engineering hours has reduced dramatically. The modular design of the new simulation models has also contributed to lower the engineering hours since much can be reused from project to project. The operators get to use the real displays and real control system when doing simulator training, and no changes needs to be made in the simulator when changes are made to the displays and control logic.
- It is much easier to keep the simulator system up to date since the real control system is used. Changes made to the displays and control logic can be transferred into the simulator system directly by the mill personnel.

Another big advantage with the new architecture is that the simulator system can be used to validate the upper level control system and mill control system before start-up. This has traditionally been a very time and resource-consuming task and even then, the quality of the validation has been difficult to verify due to the complexity of the control logic. Errors in the control system, as well as in the dimensioning of process equipment, are corrected easily and effectively early in the projects. Considerably reductions in test time have been noticed since starting using simulators for test purposes. As the simulations get more accurate it is also possible in some areas to pre-tune PID controllers using the simulator. Starting the real mill with verified control logic, trained operators and pre-tuned PID controllers are a great benefit for Metso Paper customers.

2 The Simulator system

2.1 Architecture

The new simulator architecture is shown in Figure 2.

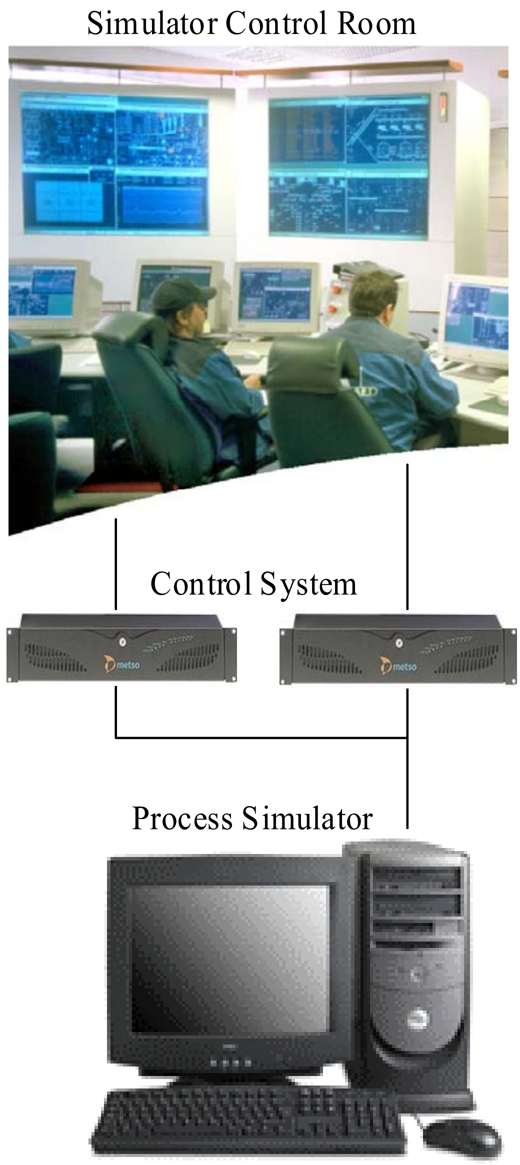

Figure 2. The new simulator architecture

A Metso Paper simulator system typically consists of a control system that is the same control system used to control the real process (example: metsoDNA, ABB Industrial IT, Siemens PCS7, Emerson DeltaV, etc). Another computer executes specific process simulation models in real-time. The operators are using the same operator displays as they would in the real control room. The system can be extended to include several computers that simultaneously are running different simulations towards the same control system. Real control system hardware can be used to execute the control logic and operator displays. However, a modern control system usually offers a software version (example Metso's VirtualDNA) of the control system, which can be more convenient to use. Included in the control system are all control logic, graphical displays, PID controllers, alarm limits, interlocking diagrams, trend displays etc. Everything that an operator will have once running the real process is already there since it is the same system being used.

2.2 Models

Using Modelica and Dymola a specific model library has been developed including models that make it possible to build complete simulations of Metso Paper machines and processes. Examples are SuperBatch™ cooking, Washing and Screening, Refining, Pulp Bleaching and Pulp Drying area. In Figure 3 a small part of the washing and delignification process can be seen.

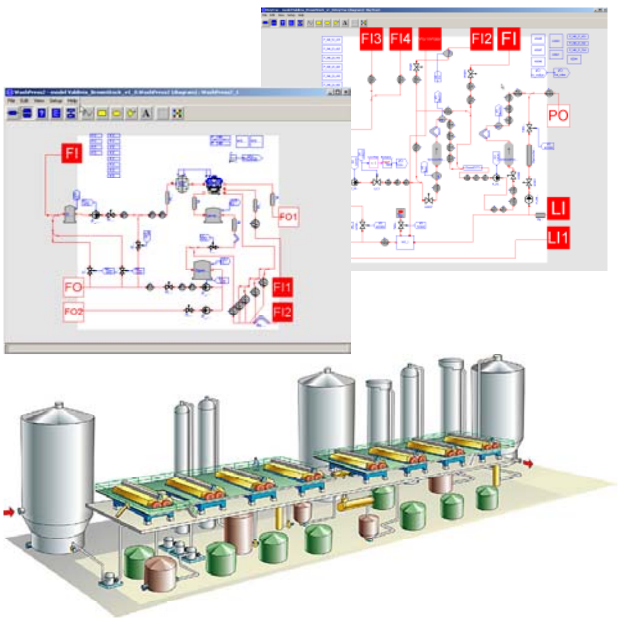

Figure 3. A part of pulp making process

The library includes models of Metso Paper specific machinery such as SuperBatch™ digesters, DeltaCombi™ screens, Refiners, TwinRoll™ presses, OxyTrac™ delignification towers and Pulp Drying machines, but also more general equipment such as valves, pumps, pipes, heat exchangers, tanks, etc. Together the models are used to build up simulations of complete pulp mills. Creating a large net of equations defining the flows, pressures, temperatures, chemical consumption, pulp consistency and other process values, all values will react depending upon the actions taken by the operator using the control system. A complete simulation includes all process machinery and instrumentation, starts with chips enter the digester area, and finish when dried and bleached pulp exits the drying machine.

2.3 Communication

The simulation models are compiled with Dymola forming a Windows application that is used as a real-time DDE Server. Modern control systems offer an OPC Server in order to open communication with any OPC Client. The Metso Paper simulator system includes special software to transfer the signals from the DDE Server in the run-time simulation to the OPC Server in the control system. Since practically all modern control systems have opened up to OPC technology the communication link can be used without changes no matter what control system the customer selects. The only configuration that needs to be done is a cross-reference list between the signal names in the simulator and the corresponding signal names in the control system. Typically are process values like flows, pressures, temperatures, pH, consistencies etc, sent from the simulations to the control system. The control system writes values like valve openings, starting orders for pumps and motors etc, back to the simulation.

Modelica models for I/O communication have been developed. They are using the input/output qualifiers to accept values from, and to give values to, the control system via the communication link.

2.4 Teacher interface

The extended functionality of the communication link includes an interface for a teacher. From this software a teacher can operate the dymosim application, start, pause and stop the simulation. It is also possible to start the simulations with different initial positions, empty tanks, almost full tanks etc. making it possible to train how to get out of difficult process situations without losing production.

Different kind of scenarios and disturbances can be applied to the simulations to investigate how operators solve and detect common process problems. Problems like drifting process values, malfunction in valves, blinding of screens, channeling in reactors, web break in the dryer section as well as other criti cal situations can be trained. Figure 4 shows screen displays from the teacher interface.

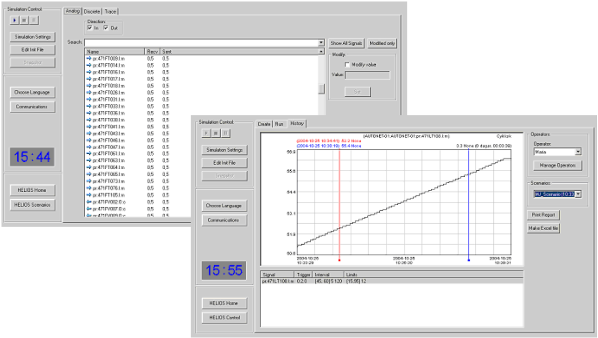

Figure 4. Teacher interface

A large database is used to collect data from the training sessions and each operator can evaluate their actions and compare the results with earlier sessions.

2.5 Performance

Due to the complexity and scope of the process to be simulated the simulation model files and I/O communication lists becomes large. For example when simulating a SuperBatch™ digester area the I/O list consists of about 1800 signals, the executable simulation file is close to 40 Mb. Figure 5 shows messages from a translation of a digester area model.

STATISTICS

Original Model
Number of components: 20084
Variables: 137615
Constants: 1574 (0 scalars)
Parameters: 35394 (69071 scalars)
Unknowns: 100647 (100658 scalars)
Differentiated variables: 9146 scalars
Equations: 52124
Nontrivial : 39885

Translated Model
Constants: 53502 scalars
Free parameters: 17018 scalars
Parameter depending: 19966 scalars
Inputs: 0
Outputs: 0
Continuous time states: 9146 scalars
Time-varying variables: 42482 scalars
Alias variables: 24590 scalars
Number of mixed real/discrete systems of equations: 18
Sizes of linear systems of equations: {2, 2, 2}
Sizes after manipulation of the linear systems: {0, 0, 0}
Sizes of nonlinear systems of equations: {5, 732, 35, 35, 66, 38, 7, 14, 35, 7, 35, 18, 66, 18, 35, 7, 14, 35, 7, 14, 7, 7, 14, 35, 7, 35, 7, 7, 5, 1, 7, 23, 6}
Sizes after manipulation of the nonlinear systems: {1, 89, 4, 4, 9, 2, 1, 3, 4, 1, 4, 2, 9, 2, 4, 1, 3, 4, 1, 4, 1, 1, 3, 4, 1, 4, 1, 1, 1, 1, 1, 3, 1}
Number of numerical Jacobians: 0

Finished

Figure 5. Translation of a digester area model

The digester area is about 25% of the total pulping process. It is possible to run these kinds of simulations on a PC. However, the speed of the internal memory bus is vital to simulation performance. Due to the slow nature of pulping processes, it is common that the simulations are run for several days without interruptions.

For training purposes it is very important that the system is robust and that the accuracy is high enough for the operators to trust the simulations. However, it is important to keep in mind that the purpose is not to simulate each process component as accurately as possible. The purpose is to produce a simulation of a large area including a large amount of equipment that will give an operator the right look and feel for the dynamics in the mill.

3 Practical experiences and future development

Today the simulator system has been connected to the following control systems: metsoDNA, ABB Industrial IT, Emerson DeltaV and Siemens PCS7. There are of course advantages and disadvantages with all of these systems when it comes to engineering efficiency and costs, but from our point of view; there are no technical differences. The same communication link has been used without modification, and the signal transferring between an OPC Server included in the control system and the real-time simulations has shown a similar performance with all mentioned control systems. Two complete simulator systems have been delivered so far. Figure 6 shows operator training in Chile. During 2005, three more deliveries are expected.

Figure 6. Simulator training in Chile

During the internal development work and practical training sessions with Metso Paper customers around the world some development ideas have emerged. The ideas, if emasculated, would heavily increase the value and competitiveness of using Modelica and Dymola in combination with control systems for real-time simulations. Some of the most important areas to strengthen in order to meet industry demands in the future are as we see it:

- Replacing the Dymosim DDE Server with a modern OPC Server will open the simulation environment to all modern control systems and increase the communication performance significantly. Many OPC Clients are available on the market, some even free of charge. Viewing and changing simulator values during run-time simulation would be facilitated.
- A possibility to see and change simulation values from the modeling user interface during run-time simulation would be very time saving and valuable during development of large simulation models.
- Increased debugging functionality. When a model for some reason crashes after several days of simulation, it is very hard to find the reason quickly. The large simulation models and long simulation time makes it difficult to store values for debugging due to the huge amount of data collected.

4 Conclusions

Dynamic process simulation is a powerful tool when educating new operators in running a pulp mill. Successful real-time simulators using Dymola/Modelica with control system in the loop have been used for control system validation and for operator training in Metso Paper processes. The strong modular focus in Dymola/Modelica have been helpful in reusing simulation models and thereby shortened the engineering hours in new projects.

Some proposals of improvements to Dymola/Modelica has been made in order to strengthen the focus, increase competitiveness and general awareness of using Dymola/Modelica in industry applications.