EXPERIENCES AND TRENDS IN MODELLING AND SIMULATION OF INTEGRATED INDUSTRIAL PROCESSES

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Abstract

Modelling and simulation should efficiently support all engineering and operational processes during the complete life-cycle of an industrial plant. However, modelling of an integrated industrial plant has been and is still a very challenging endeavour because of the huge number of details that needs to be considered. The manual extraction of required model specification data from various sources has still required availability of dedicated mathematical modelling experts and the working procedures have been very time consuming, expensive and error prone. The resulting large set of heterogeneous equations has required both efficient and reliable solution methods and much computing power. Now there are efficient dedicated simulation tools available in the market and as well as sufficient computation power. The experienced slow take-up of modelling and simulation has been explained with that simulation has been separated from other engineering disciplines. Support for easy access to required modelling data is expected from the evolving semantic specifications of both separate components and integrated plants in accordance with ISO interoperability standards. Further, the OPC de-facto standard adopted by most DCS vendors makes it nowadays easy to connect a digital control system to a computerised process model. Testing of real control system configurations can be made in advance with models instead of real plants. Application projects in co-operation with global industrial players in the fields of power plants, pulp and paper processes, and control systems engineering are referred to. The Apros software taken into use has an own specification script that supports interfacing to other formal data repositories. The contents of useful repositories should also include such data that is needed for dynamic model specifications.

Keywords: Integrated plant models, Successful use cases, Interoperability standards

Presenting Author's biography

Chief Research Scientist Dr. Kaj Juslin acts presently as Customer Manager of Business Solutions at VTT Technical Research Centre of Finland. In addition, he teaches postgraduate courses in simulation at Helsinki University of Technology. He is a member of the Technical Committee on Mathematical Modelling of IMACS. He is also member of the editorial boards of several commercial journals in the field of simulation. He is former president of both EUROSIM (1996 - 1998) and SIMS (1985 - 1988). He has chaired several simulation congresses.

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1. Introduction

Simulation can be used and it has been used for different purposes during the whole life cycle of large industrial process. In the past the most expensive computers were needed for rigorous simulation studies. Dedicated models for separate effect studies were developed on mainframe computers by different narrow-field experts, such as neutronics and thermal hydraulics experts with regard to nuclear power plants. It has been considered as a problem to combine results of separate studies.

Accordingly, the development of a completely new simulation software tool, APROS, was initiated where the models could be specified based on the plant mechanical structures using a high level specification script. This script has enabled a streamlined connection of the simulation engine to several generations of graphical modelling and simulation interfaces.

The verification and validation issues were important from the beginning of the developments. The idea was to build a set of physical modelling elements that easily could be separately tested for required physical state and parameter conditions. It should further be easy to combine such elements representing different physical mechanisms to real process components and proceeding with test of such components. It was postulated that if they work correctly compared to available measurements in a sufficient number of process models, then they would also operate correctly in completely new configurations.

The above modular testing philosophy had strong impact on the structure and implementation of the Apros simulation engine. One of the real challenges was to manage with real world heterogeneous and only piece-wise continuous processes. How to select the variables to solve in first place was another interesting question. The correct treatment of nonlinearities was essential for success. The heterogeneous features of real processes called for tearing and grouping to enable application of different time-steps and implicit methods where needed.

Experiences on the development and use of simulation models of various types of industrial processes ere presented. The referred to simulation use cases were chosen to involve detailed models of large integrated plants. A very dedicated performance requirement of the simulation tool concerned both fast calculation and sufficient accuracy at the same time over a large operational range. The simulation software needed to run fast enough on standard PC hardware and software platforms. Easy connection to digital automation systems was expected.

As concluded from the studies, these requirements have been met. The developed models have been used for optimising process and automation design, for safety evaluations, for control system testing, as well as for development of operational procedures and for operator training. However, new expectations have arisen in an engineering context that is focusing on the integration of modelling and simulation with other design and evaluation tools. It seems that it is indispensable for an efficient use and a larger take up of dynamic simulation in the engineering work practices that the modelling work is intelligently supported as far as possible and it should for instance not be required to involve of modelling specialists in real application projects. Also, it should be easy to connect the simulator platform to other engineering tools and databases, such as evolving semantic plant data repositories. Redrawing of diagrams and refilling forms should be history. Concurrent modelling and validation activities in workgroups should be supported. Efficient and reliable version handling is a must. Ubiquitous access to the simulation models should be possible for relevant personnel involved with design, operation or maintenance of the plant. Ongoing international standardisation work for interoperability empowers the required developments.

2. Verification, integration and validation

The basic requirement for developing the APROS code was to get a tool that is capable to calculate the behaviour of industrial processes at a large operational range including normal operation with start up and shut down procedures and postulated accidental situations like large sudden pipe breaks [1]. In many cases full scale integral tests on real plants for the purpose of model identification or validation can not be made, for instance, the plant has not been built yet or the economical and secure operation of the plant does not allow for relevant tests. The dynamic performance of a modern industrial plant depends not only on the process design itself but also to a large extent on the control system implementation. Accordingly, the modelling work needs to rely on available information such as the geometrical structure of the process, known material properties, known chemical or nuclear reactions, basic equations for continuation of mass and energy, and, when available separate effect tests made with dedicated test facilities. Of course, the model can be fine-tuned when accurate enough measurements are available from real plant. In practice the impact of the achieved flow velocities on heat exchanger surfaces and the actual level of fouling need to be considered. However, the use of measured data for model validation can sometimes be problematic because of measurement inaccuracy. The accuracy of each measurement should be known and considered. On the contrary, integrated models have been used for data reconciliation calculations in order to correct measured data.

An additional requirement was that it from engineering point of view should be possible to build up a larger plant model by hierarchically combining sub process models starting from separate process component models. The requirement was further extended to enable construction of process components from elementary models arising from flow and heat conduction structures. For validation purposes, a certain number of test equipments were modelled with the elementary components and the simulation results were compared to a certain number of measured tests. It was postulated that if the combinations of elementary models works correctly for these comprehensive tests, they are also supposed to calculate correctly in other combinations and in other transients. In practice, this means that each new version of APROS needs to pass a comprehensive series of validation tests before release.

The resulting requirements on the elementary models are quite extensive. They should for instance allow for change of flow direction during the calculation. They can accordingly not be strictly unicausal input-output models like the transfer functions in control system studies. They should allow for easy connection to other elementary models, for instance attachment of several pipes to one connection point. In addition, it should be possible to apply any required materials in relevant structures and flowing media of the elementary model.

The final requirement was that it should not be needed to write any equations, or to perform any software programming, compilation and linking procedures during the modelling of the target process. In an engineering project there is no time for such luxury because completely new programmed models would require subsequent extensive validation work.

3. Implementation issues

3.1 Real world heterogeneous processes

The real word processes can be claimed to be discontinuous, non-linear and heterogeneous. Each of these features will be discussed separately. By making some additional assumptions sufficiently efficient solution methods can be applied. Real word industrial processes are usually stiff because they involve a very large range of time constants. Therefore, implicit methods are preferred to ensure required stability of the solvers.

3.2 Piece-vice continuous time-intervals

An additional assumption is that a certain part of the process performs piece-vice continuously between the discontinuity points. This helps to design the solution procedure, however, the exact timing whence passing a discontinuity point needs to be found. The world may behave linearly or non-linearly between the discontinuity points. The exact timing requires an iterative approach. Benefit can be made from Newton type of estimation of the discontinuity point, such as the change of flow direction and resulting closure of an involved check valve. Figure 1 illustrates the operation of a check valve and the iterative estimation of the time step to successively reach the closing point of the valve. Subsequent adjustments of the time-steps are indicated to reach the exact time for closing of the check valve whereas **m** denotes the mass flow through the valve and **t** the elapsed simulation time.

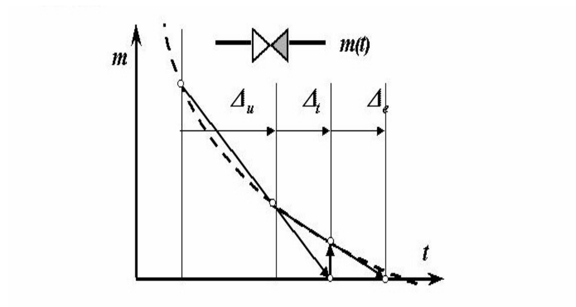

Figure 1. Adjustment of the time-steps

3.3 Correct selection of variables to solve

If the world is assumed linear then we can only study small perturbations around some steady state operation point. Correction for non-linearity is however not very easy when applying implicit solution of the nonlinear behaviour between the discontinuity points. At each new time step as above the implicit solution needs to be iterated, as well, to correct for nonlinearities. Just looking at the nonlinear mass flow in a valve depending on the pressure difference over the valve according to Figure 2 gives some hints on the scope of the problem. The proper selection of each unknown variable for iterative correction is required for convergence whence solving the whole integrated nonlinear system. Applying Newton type of gradient based iteration results easily in divergence if the mass flows are chosen as unknown variables in an integrated network. However if the internal pressures in the network are chosen as unknown variables the solution will converge, and in addition, very rapidly.

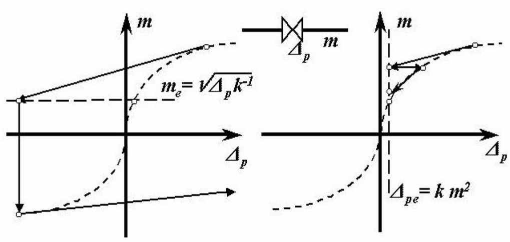

Figure 2. Diverging and converging iterations

This example on turbulent flow is, however, somewhat simplified. It is assumed the resistance coefficient would be constant. In fact it is depending for instance on the on the density and the viscosity of the flowing media. Further, the actual flow velocity in the valve can not exceed the velocity of voice in the fluid at the prevailing state in the valve.

3.4 Adjacent monotonically nonlinear regions

In practice we have to cope with multidimensional correlations. Looking for instance at the density ***D*** as a function of pressure ***p*** and specific enthalpy ***h***, we need to consider nonlinear surfaces. If the nonlinear regions can be divided into monotonic (monotonically increasing or decreasing) sub regions the problem can be solved efficiently because Newton based iteration for correction of nonlinearities can be applied. Applying the concept of monotonic regions the stability of the iteration can be assured if the regions are extended monotonically for the time of iteration as shown in Figure 3. Logarithmic density surfaces for water (left) and two phase region (right) as a function of pressure and enthalpy. The water region is extended monotonically downwards as sub cooled and the two-phase region is extended upwards as superheated.

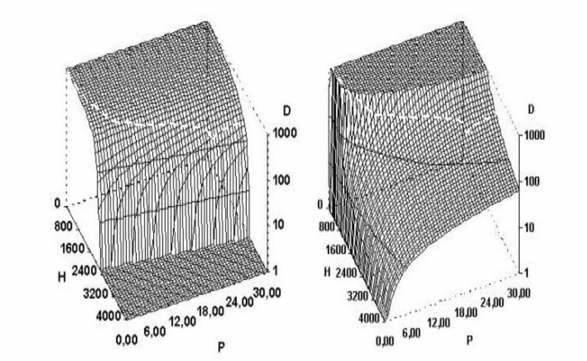

Figure 3. Logarithmic density surfaces

3.4 Grouping to avoid round-off errors

A practical measure for the heterogeneousness of for instance a linear electrical network could be specified as the maximum ratio of conductance of adjacent branches in the network. It is often assumed that a heterogeneous set of equations can be divided into more or less homogeneous clusters. For instance, involving physical mechanisms with same magnitude of the time constants in each separate cluster, helps to build up a numerically stable integrated solution. Different time-steps might be needed for simulation of such separate clusters to avoid spatial and temporal discretisation errors as well as the seldom thoroughly considered round-off errors caused by a restricted number of digits available for storage and processing of each variable. Usually an optimal time step interval with regard to achieved speed and accuracy of the calculation can be found. Sometimes the control system requires such a short measurement interval for a part of the process that it does not make sense to calculate the whole system with that time step. A too long time step might result in discretisation errors and increased number of iterations whence a too short time step might cause severe round-off errors and result in numerical instability. Truncation errors, on the other hand, that originate from too early interruption of iterative correction procedures are easier to check and control.

3.5 Intelligent spatial discretisation is required

Both distributed parameter models and averaged parameter models are used whence modelling real world performance. Distributed parameter models are usually applicable for detailed studies of a smaller domain of a system. Building up an integrated model from distributed parameter submodels is a challenging task. In real world integrated systems very often averaged parameter models including spatial discretisation are used. Internally the resulting control volumes are considered to be homogeneous, same averaged temperature, same averaged density, and so on. The LaGrange approach supposes that the control volumes move with the averaged speed of the mass of the volumes. Euler's approach is that the control volumes are stationary and the balance of masses leaving and entering the volume is considered.

How to make the required division of real world space into control volumes? Obviously, where there are more changes there the control volumes needs to be smaller and denser than and where equilibrium prevails. Sometimes, when the region of large changes moves the division into control volumes needs to be adaptive. An intelligent division into control volumes may help to obtain homogeneous clusters of equations and to accordingly avoid numerical problems. Sometimes spatially evenly distributed control volumes are sufficient.

A typical approach of the division of a counter current flow heat exchanger into control volumes is indicated in Figure 4.

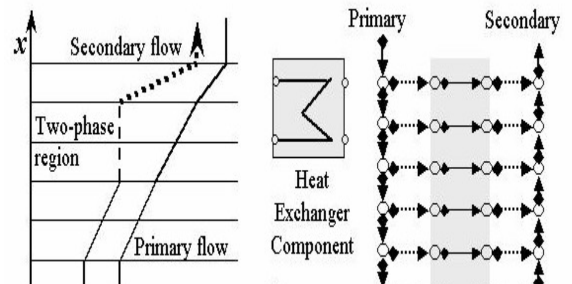

Figure 4. Heat exchanger nodalisation and relevant temperature distribution

A steam generator modelled as a counter current heat exchanger has been spatially discretized into control volumes, here denoted by nodes. There are control volumes both for heat structures and flow structures. The branches between the nodes symbolise the flow of mass or energy between the control volumes. Typical for real world heterogeneousness is in this case that the specific volume of the fluid changes with several orders of magnitude whence passing the component. The spatial location of the two phase region indicated in the figure may change, as well.

Structured graphs are needed for specification of the behaviour of multiple state variables within the same control volume, such as pressure, enthalpy, concentrations or multiple mechanisms such as compressibility, heat accumulation, reactions or mass flow of substances. A compound node connects two compound braches in Figure 5. Each compound branch includes simple branches depicting mass, energy and three separate substances. The simple nodes related to pressure p, specific enthalpy h, and mass fractions c1, c2, and c3 are further connected to vertical branches depicting accumulation of mass, energy and substances. In addition there are local branches between the concentration nodes indicating chemical reaction rates.

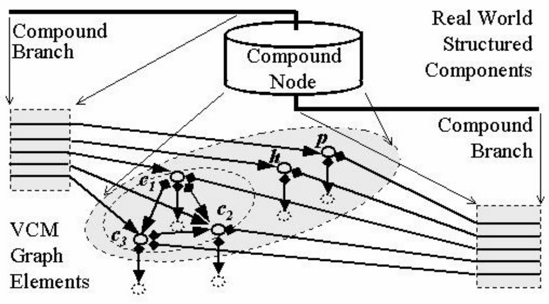

Figure 5. A reactor tank as a compound node

The set of equations arising from a proper spatial discretisation of a complete plant may include tens of thousands of partial differential equations. For real-time or faster solutions of such systems dedicated partial equation solvers are needed. Of course, it may also be possible to solve these kinds of equation systems with general purpose simulation tools. In practice, however, a huge amount of dedicated manpower and very much calendar time has already been invested in optimizing existing special purpose thermal hydraulic solvers for real-time full- scope applications [2, 3, 4, 5, 6].

3.6 Implementation aspects

There are many ways to specify equations of a simulation model and to implement relevant solvers needed for simulation studies. In procedural modelling explicit input variables $\boldsymbol{x}$ and output variables y are specified and related equations $\boldsymbol{y=f(x)}$ are sorted and programmed in a specific sequence. Declarative modelling, however promotes the use of implicit dependencies, such as $\boldsymbol{f(x,y)=0}$. The previously considered requirement to facilitate for changes of flow direction in pipe networks can be met with implicit solvers. On the other hand, control system blocks with inputs and outputs are intrinsically procedural. Accordingly, both approaches are needed in parallel.

Continuous industrial processes have a networked structure. The relationship between physical systems and linear graphs was recognized already 50 years ago [7]. It seems obvious that attempts to automatically generate simulation models from structural plant specifications needs to be based on linear graph representations. The graphs comprise nodes and edges. The nodes represent local properties at the connection points of the branches, such as voltage, pressure, specific enthalpy, or mass fraction. The branches represent transition variables between the relevant connection points, such as current, mass flow, energy flow, or substance flow. It is to be noted that there is no accumulation in a node itself, the accumulation of charge, mass, energy, or substance is supposed to take place in relevant branches.

The basic performances of thermal dynamic processes in consideration are noted by relevant partial differential equations. The conversion from these nonlinear equations to linear graph equations needed to be solved for each iteration at each time step in an implicit approach can fortunately be made in advance for each physical mechanism to be considered and is therefore transparent to the modelling engineer who may fully concentrate on his application project.

The conversion includes the spatial discretisation, the temporal discretisation and the momentary linearization. The decision on the spatial discretisation, that is, in how many control volumes a long pipe needs to be divided for accurate enough calculation of the transients in consideration, is however often left for the consideration of the user. There is a general rule, Courant's criterion, that the transient studied not should move longer than the distance between the centres of two control volumes during one time step. This was already concluded some 40 years ago [8].

As resulting from the spatial discretisation of the partial differential equations, a set of ordinary differential and algebraic equations is attained. There are several possible approaches to solve this DAE system. One possibility is to identify suitable "state variables" of the algebraic equations and make them "dynamic" introducing small time-constants and solving the accordingly extended set of ordinary differential equations by library routines, usually explicitly. The benefit with the explicit integration is

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that the nonlinear coefficients do not need to be momentarily linearized. On the other hand, the explicit integration may require a very short time step for stability. It can usually not be longer than the shortest time constant in the relevant system. This approach has usually been applied if the starting point for the modelling is a large set of user given explicit equations.

The other approach, conveniently suiting the graph based process specification, is to choose the most suitable implicit integration algorithm for each type of ordinary differential equations involved, and perform the temporal discretisation symbolically, accordingly ending up with an implicit nonlinear algebraic equation system. As indicated previously a suitable Newton method can be used for iterative correction of monotonic nonlinearities. For each iteration the linear matrix equation system arising in each domain in the form $A\underline{x} = \underline{y}$ needs to be solved. The efficiency of this method depends much on the successful application of sparse matrix methods. It is beneficial to solve different homogeneous domains separately that represent phenomena advancing with very different transient velocities, however affecting the same integrated system. For instance, the pressure advances with the speed of voice in relevant medium (e.g. 1000 m/s) and the energy and concentration solutions with the speed of fluid flow (e.g. 1 m/s), and the diffusion in heat structures (e.g. 0.01 m/s).

3.7 Versatile companion model

The versatile companion model seems flexible enough to manage with above considered implementation issues. The linear dependency between two local variables x_i and x_j and relevant transition variable v_{ij} can be written as $x_j\, g_f - x_j\, g_b + s_{ij} - v_{ij} = 0$, where g_f and g_b denote the forward and backward coefficients and s_{ij} the source term. The relevant versatile companion graph is shown in Figure 6.

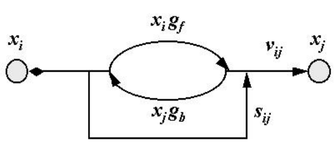

Figure 6. Versatile companion model graph

The coefficients are considered as constant for the time of each iteration step only in an implicit solution scheme. If $g_f = g_b$ the related branch is considered A-causal. If both of the coefficients exist but $g_f \neq g_b$ hen the branch is considered Bicausal. If only the other coefficient exists the branch is Unicausal. If both coefficients are zero and only the source coefficient is left then the branch is called Forced. If also the source term is zero the branch is Disconnected. Changes in causality during simulation need to bee considered accordingly.

The versatile companion model supports both procedural and declarative modelling. The local variables or transition variables referred to by the versatile companion model may, accordingly represent a boundary condition, an estimated value, a implicitly calculated value, a previous iteration step value or an old time-step value. The versatile companion model flexibly supports different application domains as set forth in Table 1.

-Domains	Transition v_{ij}	Local x_i	Local x_j
Electrical circuits	electrical current	voltage	voltage
Hydraulic circuits	mass flow	pressure	pressure
Convection	energy flow	specific enthalpy	specific enthalpy
Heat structures	energy flow	temperatu re	temperatur e
Fluid to wall	energy flow	specific enthalpy	temperatur e
Concentrat ion	substance flow	mass fraction	mass fraction
Chemical reaction	production rate	mass fraction	mass fraction
Rotating mass	shaft power	rotation speed	rotation speed
Electrical power	complex current	complex voltage	complex voltage
Control systems	not applicable	control signal	control signal

Table 1. Local and transition variables of different domains

4. Example use cases

Apros is in use at hundreds of installations all over the world. The scope of users is very broad, including plant users, equipment manufacturers, plant manufacturers, control system manufacturers, consultancy providers, research organisations, schools and universities. Apros is used for design and analysis as well as training purposes. The industrial areas cover nuclear engineering, combustion power plants, pulp and paper mills, and chemical processes.

4.1 Multifunctional tool for Loviisa

The Loviisa nuclear plant including its control system has gradually been modelled according to the needs of performed analysis studies. One original reason underpinning the decision to develop Apros was the need to include more detailed automation system functionality in the analysis of postulated accidents in nuclear power plants. The existing nuclear plant analyser codes were usually considering main flow circuits and were not very well suited for control system model extensions.

The once developed models for the Loviisa plant came into use again a few years ago for the purpose of increasing the rated power level of the plant. The modifications required were applied to the model and the large set of original transient analysis, were easily repeated with Apros. The safety analyses were needed to prove that the uprated 1500 MWth power level of Loviisa nuclear power plant does not cause any safety problems. The safety analysis included dynamic simulation studies of a series of accident scenarios. The safety analysis results showed that Loviisa reactors can be safely operated on the higher power. Presently the Loviisa plant is operating on average 50 MWe higher electrical power per unit. APROS proved to be such an excellent tool on safety analysis field that Fortum Nuclear Services are currently doing practically all the safety analyses using APROS code. The earlier major tool RELAP 5 code has a role in assessing the APROS analysis results. A typical plot from a loss of coolant accident simulated with Apros is presented in Figure 7.

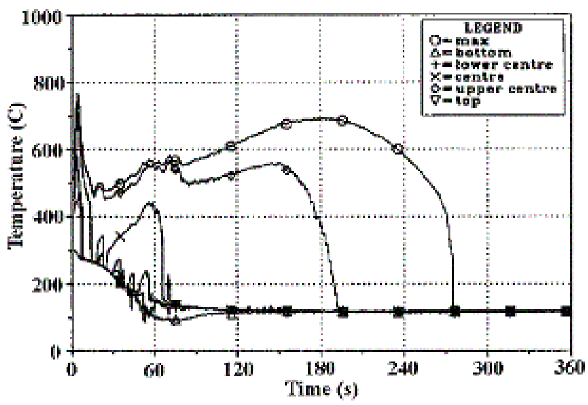

Figure 7. Fuel rod cladding temperature during loss of coolant accident

A new challenge for Apros is related to the approaching upgrade of the control system from the thirty year old analog system to a modern digital control system. Loviisa analysis model in Apros is extended with auxiliary system models for this purpose. It has already been used for testing of the design of the new digital control room functionality. The next step is to use the model for testing the functionality of the new digital control system. In addition it will serve the new training simulator connected to a copy of the new control room equipments

4.2 HAMMLAB example of extensive model

It is easy to show that it could be boring and error prone to write with some formula editor all the tens of thousands of differential equations easily included in a model of an integrated process. Just consider the extent of a simulator constructed for the purposes of control room functionality developments. This HAMBO simulator was installed in HAMMLAB in Halden, Norway, in 2000. The operator interface was developed by IFE using PROCSEE tool. The model development was made by VTT in Finland using the development tool APROS. The model includes the process, automation systems, and all the signals required for the studies of the performance of new control room equipment and solutions. The extent of the simulator can be described with the following numbers: Thermal hydraulic control volumes 2623, heat structure elements 6056, process components such as turbine sections, valves, pumps and fans 1850, electrical system bus bars 410 and control system signals 65170 (including binary signals). Roughly calculated the model has about 40000 analog state variables. Nevertheless, the whole model runs easily in real time with a time step of 100 ms installed on two ordinary PCs, one for the 3-D reactor model and the other one for the rest of the plant, including the simulated automation system. The model has been validated with measurements from the reference plant, Forsmark 3, in Sweden [10]. It should be noted that this simulator has been modelled just by drawing process and automation diagrams and filling in parameter forms without the need to write any equation.

4.3 Control system design and training simulator

A complicated new process was planned including combination of the parallel steam lines of the new natural circulation boiler and the older once-through boiler to the sliding pressure turbine generator. Efficient utilization of high fidelity full scope simulation was made in order to design and test the control and operation principles before the commissioning phase. During the simulator testing several inaccuracies in the control system implementation were found that would not have been possible to notice before start-up testing of the plant. Thus, the commissioning period was clearly smoother and faster than expected. In this project Foster Wheeler Energia Oy used the simulator innovatively for control system application planning. This offered excellent possibilities to test the control logic with full-scale dynamical simulations before the actual DCS-control system was applied. The simulation system consists of GRADES® Trainer DCS-emulator and Control GRADES simulation interface of Process Vision, CFB-model developed by Foster Wheeler R&D-centre and the high fidelity APROS simulation system. Since the simulator was utilized during the control application planning, it was possible to use a complete copy of the DCS-system in the operator training although the actual DCS-system was not available [9]. A typical simulated automation diagram is show in figure 8.

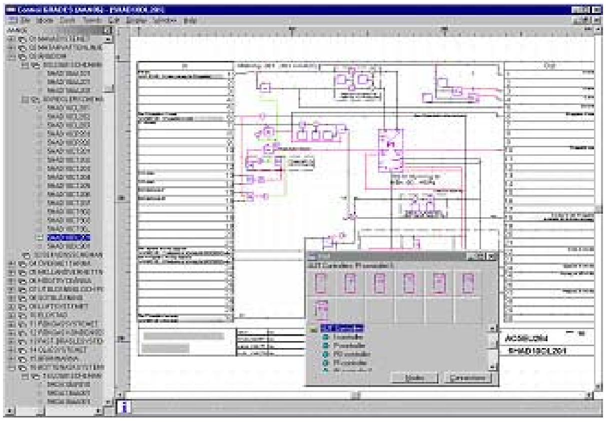

Figure 8. A window of the control grades simulation interface.

4.4 Waste to energy plant efficiency and emission limits granted.

The purpose in this use case was to grant the electric efficiency and the emission limit of an waste to energy plant. The APROS was used to model the plant, both process and automation system, in a very detailed way. The goal of the project activity was to assist the design of temperature control of the flue gases at the exit of the boiler before they enter the reactor for HCl emission control. The control strategies were tested in steady state conditions at different plant loads and for specific transients. The most efficient possibilities to manage the plant in different conditions were studied. The automation system tuning allowed granting the emission limits after the start-up of the plant. It was possible to find an automation solution that covered all the possible conditions at all the required loads of the plant. The behaviour of the plant was better understood. The confidence was improved. It was also possible to avoid any penalty payment. It was verified that a proposed process solution, rather expensive, was not necessary, and thus avoiding extra costs, delays of the plant start-up and possible further complexity [9].

4.5 Board machine grade changes faster

One of the leading paper and board producers Stora Enso Oyj wanted to shorten grade change time to improve productivity. Automatic grade change program (AGC) was tuned using a dynamic simulation model of the board machine. The accomplished process model covers the board making process from pulp chests to the end of the base board drying. The control system model includes 74 control loops. The model was built using the APROS/APMS platform. Better understanding of the process was achieved and productivity was increased because of shorter grade change time. A procedure was developed to simulate grade changes and hunt for better AGC parameter values. It was no longer necessary to rely on intuition in the tuning. The parameter changes have been carried out to the real AGC. As a result the grade change time has been shortened considerably. Because of that, the pay-back time of the simulation and optimisation project was 8 to 12 months. Modelling and validation phase helped process engineers to understand the interactions during grade changes. Additionally, they were able to spot and remove some weaknesses in operators' practices concerning the use of the AGC program. Besides the grade change development, also new applications for the model have been found. The model has already been used in studies concerning drying capacity increase and controllability with a new type of dryer. In figure 9 ssimulated and measured moisture contents at different positions of the board machine are compared [9].

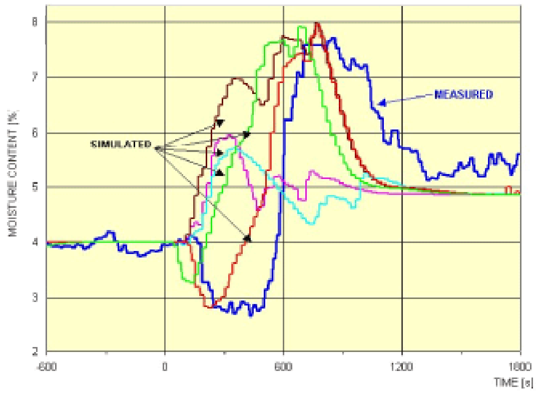

Figure 9. Simulated and measured moisture contents

4.6 Case UPM - Kymmene, Jämsänkoski, Finland

UPM-Kymmene and Pohjolan Voima Oy projected a new power plant in UPM-Kymmene's Jämsänkoski Mills. During the pre-design phase the project organisation representatives considered several possibilities for increasing the ability of the existing steam network to sustain transient situations because of increased steam capacity of the new power plant. The possible solutions were strengthening of the existing steam network, new steam accumulators, a condensing part to the new steam generator etc. Also improvement of control system design was considered. The behaviour of a steam network and accumulator of a paper mill during transient situations after increased power plant capacity needed to be evaluated. Analysis of the Steam Network was made with dynamical simulation model developed with the APROS simulation platform. The utilization of the dynamical simulator with verified physical correlations made the modelling of an existing steam network based on technical documentation possible without special and expensive measurement arrangements for model adjustment. The simulations were reported to give a clear and realistic picture of the dynamical behaviour of the plant. This helped to make the necessary investment decisions. Dynamical simulations provided good possibilities also for pre-designing of the new control systems and gave

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background information about the possible improvements of the existing process components and control systems [9].

4.7 Recovery boiler simulator connected to DCS

Kymenlaakso University of Applied Sciences provides for training purposes a recovery boiler plant model connected to Metso Virtual DNA automation system including: Drum boiler with natural flow, capacity of 5130 t/h, class room simulator facilities, and the possibility to train for instance leakage incidents. It is almost as important to invest in training of project and design personnel as for training of operating personnel. A thermal dynamics designer can e.g. test his work by operating the real boiler, practicing different operating- and failure situations that are difficult to perform with the real plant. Designers have usually no change to practice operating with the real power plant. Kymenlaakso polytechnic offers the safe option: Power plant simulator training for all professionals. "Under this kind of circumstances individual experience based learning effects to actual power plant design and operating can only be positive" [9].

5. Lessons learned in the use cases

To sum up the experiences: Models may be developed ten years before the construction of a plant. The construction may take ten years. The operation may be scheduled for sixty years. The models should support pre-design, structural optimisation of the plant, control system design and testing, postulated accident analysis, operator training, operational optimisation, plant modernisation and upgrades for many decades and for many generations of computer platforms, as well. The simulation model specifications can be seen as a mean for conveying information from designer and developers to users, and from old generations of personnel to new ones.

The performance of the models in referenced use cases has been sufficient both with regard to accuracy within required operational ranges and with regard to time step range and required speed for the real time applications in consideration.

Making extensive use of simulation tools in engineering projects require that the modelling is very efficient and that the simulation interface has provision for easy comparison of the results of continued simulation experiments with measurements from real plant when available. Usually the modelling of the main circulation circuits of an ordinary plant is made with reasonable efforts, because of restricted in number components. The modelling of all auxiliary systems is a much larger effort because of all the numerous details as it could be expected. Surprisingly, however, the really big effort is in modelling the control system, including the binary automatics and interlocks. This fact makes connection of process models to readily configured DCS systems very attractive. The advent of internationally accepted standards such as OPC enables communication between control systems of different vendors but makes it also considerably easier to connect a simulator to a digital control system. The required additional functionalities of a control system to be connected to a process simulator includes for example stop, restart, save snapshot and read snapshot. If the snapshots also include historical data of the control system then it is possible to update curve diagram history accordingly. Running modes that are faster or slower than real time are usually not available in real control systems. A fundamental requirement when taking into use a DCS system is the possibility to easily turn around all the real I/O signals of measurements and controls to access the relevant values communicated to and from the simulator. This operation should be possible to perform with a simple batch command.

The real benefit realised if the actual control system configuration files can be checked in advance with the process model and not with the real process. The control parameters can be optimised in advance. The configuration errors can be found. By experience the commissioning time can be shortened considerably. There is a place for research on how this kind of testing could be done most efficiently. Anyway, many such tests that newer could be done in real life can with preference be performed with a simulator. Having access to this kind of simulator also helps to evaluate future retrofits and developments of process and control systems, as well as optimisation of operational procedures.

After having connected a detailed enough model of the plant processes with the real DCS then a full scope simulator for the initial training of the operators has already been constructed. If it is possible to get access to an additional copy of the DCS or relevant virtual DCS running on PC hardware for a reasonable price, then the simulator is also available later on for continuous re-training of the operators. It might be advisable to order the simulator copy at the same time as the real DCS.

6. Challenges to improve work processes

Extensive modelling of control systems can apparently be avoided in future with access to virtual DCS systems. Process manufacturers would, however, appreciate a possibility to use neutral specification of the functionality required from the control system with regard to their specific processes in consideration. The equipment delivery package could accordingly include such an electronically stored supplementary information package that could be used to automatically configure the control systems of any vendor supporting a future neutral DCS configuration standard. Here the PLC systems are forerunners with regard to adoption of configuration standards. The modelling work with regard to the process equipment can in future also be automated subject that all the required plant construction data is available in electronically readable neutral format. Here, as in many other contexts, the very numerous standards and in-house conventions developed make anyone confused. There are for instance several standards available for catalogued data that can be applied to typical process components such as pumps, motors and valves. There are standards for digital transactions in business processes. We definitely need standards for integrating it all, standards that supports management of various product and process data for the whole life time of the process, 60 years and more. Now there are several actors, both vendors and end users that consider ISO 15926 as one of the most attractive solution for process plant data sharing.

International CAD software suppliers have just recently announced that they support this standard and already some large plant owners have announced that they require that equipment that they buy is documented in a standard digital format. Whence all plant data is stored in a neutral semantic format, the required 3D CAD views, 2D PI diagrams, or data needed for proactive maintenance planning and upgrading activities can be extracted. Of course also such data that is needed by steady state models, dynamic simulation models, or even structural strength calculations, can be available from either a neutral repository or through standard interface specifications between repositories. Extensive international efforts are still needed in specifying the required ontology of content for different uses and applications. The need for a multilingual reference attribute specification is obvious.

However, it seems now that the framework would be available. Labour is too expensive to be used for manual retyping of data and re-drawing of diagrams. The successful development of related business in Europe depends on fast adoption of this kind of initiatives. What is the present continuously accumulation cost of lack of interoperability? A NIST study came up with a figure of $15.8 billion per annum for the USA alone in 2006 [11].

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