EXPERIENCES ON UTILISING PLANT SCALE DYNAMIC SIMULATION IN PROCESS INDUSTRY

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ABSTRACT

This paper will consider the role of simulation in process industry and major obstacles to adopting new technologies. The benefits of process simulators are illustrated with five practical applications. These applications were realised with APROS simulator, the structure of which is explained very briefly.

SIMULATION IN PROCESS INDUSTRY

The recent advances in the computer technology have made it possible to perform complex calculations efficiently and even faster than real time. Complicated dynamic equations can be simulated and the results used in model predictive control systems, on-line process optimization, fault diagnosis and production planning.

A good process simulator makes dynamic simulation a powerful tool throughout the complete life cycle of a plant: from pre-engineering and commissioning planning to operator training and troubleshooting. These different areas are illustrated in Fig. 1.

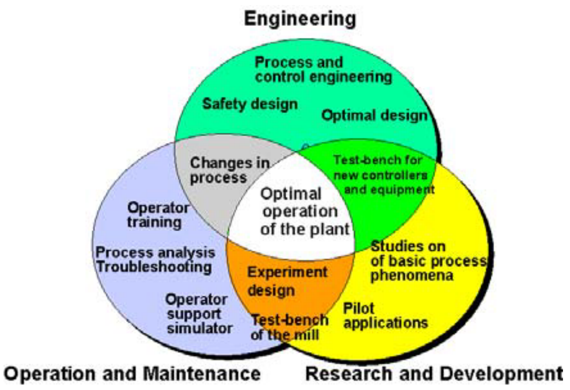

Figure 1: Role of a simulator in process industry

In a typical chemical plant, for example, the behaviour of individual reactors, distillation columns, and pumps can be monitored continuously, and process parameters changed automatically in real time to maintain desired setpoints. The behaviour of the entire plant is also monitored and setpoints can be altered in order to maximize profit on a daily or even hourly basis in response to variations in feedstock and product prices and utility costs.

In scope of all that is said above, process industry in general is playing by the ear, when it comes to the critical area of forecasting and maintaining production from a field. In many cases the plant is considered as a 'black box' with heuristic rules of thumb. Production data is rarely compared with expectations from simulations done in the early stages of field development, and problem areas are often treated on an ad hoc, individual basis without considering the influence of the other areas. The consequences of individual actions of operators are seldom linked to surprising and unwanted side-effects – especially if the distance of side-effects from operating point is far in time and space.

The main reason for flying blind by not using advanced e.g. modeling and simulation techniques is the “if it’s not broken – don’t fix it” syndrome. Adopting new technologies requires work and other resources, which has to be justified. The plant and its processes have been running for a long time and as long as the plant is running there is no need to fix it. The question whether the plant is running optimally and how significant improvements in quality, operation and profit could be made by new technologies is seldom raised.

Another major factor contributing to the reluctance to adopt simulation aided technologies is the established view that modelling and simulation is something extra that is nice to know but not necessarily needed. In planning, design and improvement projects modelling and simulation is not included in the project plan and consequently does not have any budget.

Even people who are familiar with simulation and use it to their benefit often consider simulation to be best suited for small subsystems, e.g., one chemical rector but not applicable in large scale systems, i.e. the entire plant. With this view any optimisation routine only finds local optima and it has been shown in many cases that even though every individual component is locally optimal the entire plant can be operating badly and very far from global optimum.

Many consider the lack of tools and services to be a significant hindrance to new technologies, but in most

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cases they have not been looking very hard. There are armies of simulation experts, service providers and simulation tool vendors just waiting to help plants in need – for a monetary compensation, of course. There is no such thing as a free dinner. If they are looking for a free tool just designed for their particular needs, they are correct; there is a lack of such tools.

The nature of some of the processes is less deterministic than others and in many cases there are simply no measurements on the required entities. The overall mass and energy balances can be determined but the same can not be said about the concentrations of individual reaction components. For instance, if the composition of raw materials changes considerably and there are no measurements, there is no chance of accurately predicting the behavior of the entire system. In these cases simulation is seldom used, which is a shame because in chaotic unknown systems little knowledge (in the form of simple models) can gain the most benefits.

APROS

There are many different simulator tools for various simulation problems. In fact, any algorithm capable of integrating differential equations numerically can be used as a simulator for dynamic systems. For large scale systems in the process industry it is not usually worthwhile to start from the scratch – in these problems a modular simulator consisting of smaller pre-modelled process/equipment components is the right way to go.

APROS (Advanced PROcess Simulator) was developed by the Technical Research Centre of Finland (VTT) and Imatran Voima Co (IVO). Originally the simulation environment was built for the needs of the nuclear and conventional power industries. It can be used for training, research, automation design and process design purposes. It provides solution algorithms and model libraries for the simulation of different flow and heat transfer processes. The simulation system can be defined by using the APROS command interpreter or the graphical interface Grades. A view to Grades is presented in Fig. 2.

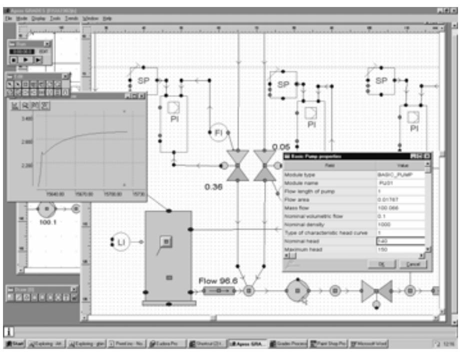

Figure 2: Grades graphical interface for APROS

The calculation is based on physical principles and empirical correlations. The network oriented solvers of APROS are table-driven, and accordingly, no programming, compilation or linking is needed during model development and simulation runs.

Apros can be furnished with generic model libraries for several types of processes such as:

- Combustion power plants – Apros Combustion
- Nuclear Power plants – Apros Nuclear
- Pulp and paper mills – Apros Paper

Apros supports the use of dynamic simulation in all different phases during the life span of a process plant, avoiding unnecessary data transfer and reconfiguration of the simulation model. Apros enables the use of an engineering simulator application as a basis for a training simulator. Once the process simulation model has been completed in the design phase it can be re-used with DCS (Distributed Control System) as a checkout and operator training tool in a cost-effective way.

INDUSTRIAL APPLICATIONS

There are five different industrial applications presented in this paper. Two applications describe training simulators for Mälar Energi ab in Sweden and Suomenoja power plant in Finland. One application describes a case in which the simulator was used for automation testing and control design in Narva power plant, one presented application shows a grade change optimisation in a Stora Enso paper board mill and another application a safety analysis in Loviisa Nuclear power plant – both in Finland.

Narva Power Plant

The Estonian power plant at Narva is an oil shale combusting power plant that consists of 8 units each with two boilers and one steam turbine. Each unit has an electric output of 200 MW. The plant is of Soviet make dating to the 1970's.

In 1999 - 2000 Fortum Engineering carried out a modernisation project of one unit, in parallel to which a full-scale dynamic simulation model on the unit was built. The process was modelled using APROS, and the automation was implemented in the virtual metsoDNA environment, all running in Windows NT environment on standard PCs. The systems were connected through their OPC interfaces. At the highest there were about 2000 signals conveyed simultaneously through this link.

The simulation model was used for testing the automation, mainly concentrating on the control loops. The testing procedure was rather similar to the control loop commissioning procedure at site. The loops tested included steam temperature, steam pressure, drum level, flue gas oxygen, electric power, feedwater tank pressure and mill temperature control loops. The testing uncovered a number of flaws in the control application, which resulted in a shorter commissioning time.

Figure 3: Narva Power Plant simulator

Additionally, different variations of the master control were tested by simulation and compared. The master control of the power plant includes the control of the electric power, turbine initial pressure and pressure in the two boilers. After the operation in steady state and in load changes was checked, it was verified that the control loops worked properly in certain disturbance situations, including a forced draught fan trip, a fuel mill trip and quick bypass of the preheaters.

Mälar Energi Ab

Process Vision Ltd supplied a training simulator to Mälar Energi Ab, Västerås, Sweden for the new CFB boiler by Foster Wheeler Energia Oy. In addition to operator training, the simulation system was used by Foster Wheeler Energy for control system application planning before implementing the actual DCS system. The process concept was unique, and simulation gave the project parties confidence in the process design.

The simulation system consists of Trainer Grades DCS emulator and Control Grades simulation interface by Process Vision, CFB model by Foster Wheeler R&D centre and Apros simulation engine.

In control application planning, Control Grades toolkit was used for building a simulation model of both the control system and the process in the simulation engine and for testing the control application plan using the models. The toolkit features page templates for documentation, an easy-to-use signal cross-reference mechanism with automatic reference texts and versatile project management tools.

The operator displays for the simulator were built up with the Trainer Grades DCS emulator package utilizing information entered in the previous phase. After that, the dynamic behaviour of the boiler was studied, e.g. the challenging combination of the parallel steam lines of the new natural circulation boiler and the older once-through boiler to the sliding pressure turbine generator. Also the preliminary controller tuning and adjusting of various set point curves and other parameters were accomplished with the simulator.

The system gave a unique opportunity to train the operators well before the commissioning period of the new boiler. It was possible to use a complete copy of the DCS system in the operator training with the look and feel of the plant, although the actual DCS system was not available.

From the end-user's perspective a significant benefit from simulation was in this case that despite the unique process concept the operators were able to confidently take over the plant at commissioning.

Suomenoja Power Plant

The Suomenoja power plant, owned by Espoon Sähkö Inc., generates electricity and district heat for the municipalities of Espoo, Kirkkonummi and Kauniainen in Southern Finland. The Suomenoja plant is powered mainly by coal (60%) and natural gas (40%), and it has a high production effeciency due to the combined production of heat (350 MW) and electricity (120 MW).

In addition to several automation deliveries to Suomenoja power plant since the year 1986, Metso Automation supplied an advanced training simulator for a pulverized coal-fired power plant unit So1 in December 2000.

The supplied simulator system consists of the virtual metsoDNA environment and the Apros dynamical process simulation software, both of which have OPC data access interfaces, and OPC-based communication software. The system runs on two standard PC's, and it is operated through real operator stations.

In the virtual metsoDNA environment, the process control applications are executed exactly as in the real system on the plant, using the original application configuration without modifications. The virtual metsoDNA has simulator features, e.g. saving and loading the state, and freezing and resuming execution.

The scope of the simulation model was specified together with the customer. There are about 1300 simulated I/O connections and the simulated process areas include:

- feed water and steam
- air and flue gas
- coal pulverizers and coal feeding
- oil feeding and burners
- steam turbine and district heat

In addition to operator training, the simulation system was later used for planning of operator actions.

Stora Enso

One of the leading paper and board producer Stora Enso Oyj wanted to shorten grade change times to improve productivity. An automatic grade change program was tuned using dynamic board machine simulation model.

The board machine in question produces 3-ply packaging and graphical boards having basis weight area of 170-350 g/m2. Typically there is at least one GC per day on the machine. The changes can be big, for example basis weight changes normally 20 g/m2 or more.

It is very challenging to try to figure out the right actions needed to improve GC performance using just a mind model. In a multiply machine like this the number of tuning parameters of the AGC is as remarkable as 84 and describes the complexity of the tuning. Different ideas compete and conflict. The simulator was seen as a possibility to test new ideas before anything is done on the machine.

A decision was made to use simulator to get better undestanding of the factors affecting on the grade change (GC) time, and to optimise the tuning of the automatic grade change program (AGC).

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 Paper platform.

The focus was on optimising AGC parameters that define the mutual coordination and rates of the ramps of the controlled variables. To be able to do that, the simulator must confidently predict the effects of the simultaneous changes in operating variables.

Simulator was validated against measurement data from real GCs on the machine. Number of reference GCs was over 50. During the validation work, undesirable operator actions in using the AGC, were noticed. After these faults were identified, the operators were advised to the optimal and consistent use of the AGC.

After confidence was gained that the simulator can consistently repeat the GCs that have been made in the real machine, the what-if experiments were started. Fig. 4 shows some results of such what-if experiments. In the simulation runs different AGC parameters were experimented with.

Simulations concentrated on speeding up the GC's simply by increasing the ramping rates of those variables, which most often limited the total ramping time. One by one higher rates were tried out and the effects on the performance analyzed.

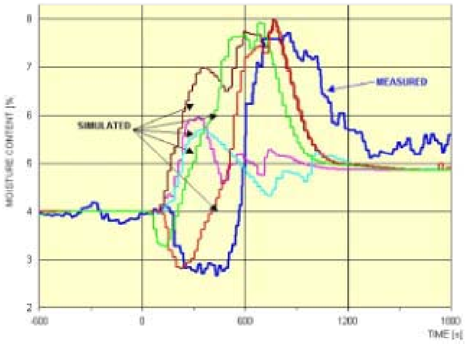

Figure 4: Grade Change scenarios

After extensive testing with the simulator, the best set of tuning parameters were taken into production use on the real machine. The machine's GC performance was monitored before and after the changes and positive development was observed.

For a multi-ply process, it is a demanding task to figure out how the automatic grade change program (AGC) parameters should be changed to speed up grade changes and simultaneously maintain high paper quality. The simulator helped to cut the problem into pieces, and offered a way to visualize the problem and compare the solution candidates. 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.

Modeling 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.

The developed model offers a platform for troubleshooting, related to GCs or other issues on the simulator's scope. Conserning the development of GCs, with the existing simulation model it can be quickly checked if a new idea is worth of further studies. Additionally, the model offers an excellent basis for development of training or operator support simulator.

Loviisa

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. Main tool in the analysis work was APROS Simulation Software.

A feasibility study for modernizing the two 465 MWe VVER units of Loviisa Nuclear Power Plant was carried out starting in spring 1994. During the study no technical, safety or licensing issues were identified which would have prevented raising the reactor thermal output up to 1500 MWth from the level of 1375 MWth. Thus the modernization project including a 9.1 % reactor power uprating was launched in summer 1995.

It was obvious from the very beginning that reactor power uprating would bring about a need for extensive revision of the Loviisa Final Safety Analysis Report (FSAR) including the safety analyses. It was also clear that tasks related to the safety assessment by appropriate computer codes and models would be on the critical path on the project schedule. That is why this work was started at the same time as the project organization was put together and the master plan prepared. The intention was to increase in the plant capacity, by about 50 MWe per unit. This was planned to be achieved by a combination of reactor thermal power uprating and by improving turbine efficiency.

The uprated reactor power was expected to raise the temperature difference over the reactor by three degrees and the temperature of the sea water trough condenser by one degree.

The analyses were needed to update the Loviisa FSAR to correspond to the uprated 1500 MWth power level and thus to prove that power uprating does not cause any safety issue.

In 1995 Fortum Oy (former Imatran Voima Oy) decided to implement Loviisa modernization and power uprating project major. The major part of the revised Loviisa FSAR thermal hydraulic analyses were calculated using the APROS simulation software.

A completely new simulation model of Loviisa NPP was build for the project. This was to ensure that all the input data was correct and the sources properly documented. The model included whole primary circuit including safety systems, steam generators, steam lines and safety critical automations systems. The model was extensively validated against measurement data from the plant commissioning tests etc.

Around 30 different initiating events and scenarios were calculated and their sensitivity to various parameters investigated. Simulations were done using the uprated power level:

- Large break and small break loss of coolant accidents
- Anticipated transients without scram (ATWS)
- Primary to secondary leakages
- Several different pump trips, line breaks, blackouts and valve malfunctions etc.

Based on the analysis results 1500 MWth is a safe power level to operate Loviisa reactors from the safety analyses point of view. This result was also expected because earlier licensing analyses, concerning 1375 MWth nominal power level, had shown that the margins to the acceptance criteria were in most cases substantial.

The large break loss of coolant accident (LBLOCA) is generally regarded as one of the critical accident scenarios. That is because virtually the whole reactor core will be dry shortly after the break. The results showed that even in this case the hot rod cladding temperature can be maintained in safe region and the whole core is rewetted in five minutes after the break.

APROS proved to be an excellent tool on safety analysis field and Fortum Nuclear Services is currently doing practically all the safety analyses using it. The earlier major tool RELAP5 code has a role in assessing the APROS analysis results.

The power uprating was successfully concluded in 1999. Presently Loviisa NPP is operating at the uprated power level meaning on average 50 MWe higher electrical power per unit. Depending on the price of electricity this translates into additional revenue of 10-15 M€/year and unit.

CONCLUSIONS

On the basis of the example cases presented, it is easy to see that simulation brings about great benefits throughout the life span of a process plant.

1. The process and automation concepts can be studied and validated in the planning phase, before selecting the suppliers (case Västerås). This reduces risks in the commissioning projects and improves the mutual understanding of project deliverables within the consortium.
2. The automation application can be verified before the commissioning by using virtual automation (case Narva). This shortens the commissioning time as there are fewer flaws in the system and the personnel has done the site acceptance test operations on the simulation system before coming to the site.
3. The benefits of training simulators (cases Västerås, Narva, Suomenoja) are widely acknowledged. A simulation environment is an invaluable tool in transferring knowledge from the commissioning staff to the operators in the end-user organisation and from experienced operators to novices.
4. The control system and operative procedures can be further developed and optimised after commissioning (case Stora-Enso). The simulation

system can also be used by the end user for the planning of renewals.
5. In safety-critical industries, simulation is practically taken required for various kinds of analyses (case Loviisa). It can be estimated that in time requirements like these will spread to other industries.

As a rule, when planning the use of simulation to support a commissioning project, one should try to find more than one use for simulation in and after the project.

In the future, the standardisation of plant data models will greatly reduce the manpower, time and costs of building up a simulation model. That development is likely to make simulation a rule, not an exception.

Referred modelling and simulation services have been completed by one or several of engaged parties: Process plant supplier, control system supplier, consultancy supplier, or software supplier.

The services have been supplied during different phases of the life cycle of the plants: Validation of plant performance in postulated operational and disturbance situations, evaluation of joint operation of process and automation design, optimisation of operational procedures, testing of functionality of real control system implementations, and use of simulator for operator training purposes, as well.

Combining the scopes of the presented applications gives a view of what a whole life cycle lasting integrated service concept could provide for: Optimisation of design, mitigation of economical risks, and a long lasting competitiveness.

According to our experiences, it would be very advantageous if the plant designer, resource optimiser, personnel instructor, trouble shooter, plant operator, who ever involved, could get access to the model required for his study, ubiquitously from his PC, regardless of where he is, where the repository resides or where the model runs.

The advent of persistent process design data repositories is the key issue. Existing basic standards for semantic and ontological specifications enable the required developments. Success stories like the above, help to ensure the different stake holders of the benefits, and accordingly promote the introduction of new required practises of model supported design and operation.

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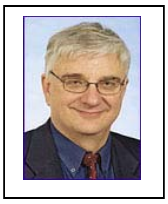

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