

Co-simulation with rigorous dynamic simulators and optimizing APC via OPC UA communication

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ABSTRACT

Optimizing production rate changes and abnormal situations of process plants induce a number of design and performance criteria for Advanced Process Control (APC). In addition to stabilizing control APC must also possess optimal performance within wide operating regions in capacity changes and abnormal situations with changing, preset criteria. This paper deals with the verification of APC against plant specific performance criteria utilizing a safe simulation environment with seamless co-simulation of two rigorous dynamic simulators. The presented simulation environment enables extended hard-testing of the APC capabilities to possess autonomous functionalities and to manage also involved environmental risks in abnormal situations. A refinery process furnace has been presented as a case study of the presented subject.

1 INTRODUCTION

Nowadays the management of companies with several plant wide operations, in addition to real-time control and optimization, total business, raw material and product logistics, needs increasingly more information of production status in real time. In managing different production scenarios based on changing product and raw material markets agile real-time control systems, different kind of dynamic process simulators, logistic simulators and business simulators are more and more needed. Consequently dynamic simulation connected also to the real time process operation is preferable for look-ahead simulation to verify the production scenarios. A challenging task is to estimate the initial state of the simulator to be close enough to the real process state. The choice of the modeling accuracy and the compatibility of the simulators of different process areas are the main items to be defined based on the planned simulator usage.

Based on these requirements a project was established to verify the usability of co-simulation with several different rigorous dynamic simulators via OPC UA communication including also optimizing APC. APC means in this case only MPC (Multivariable Predictive Control). OPC stands for open connectivity via open standards and UA (Unified Architecture) is the latest OPC standard providing a cohesive, secure and reliable cross-platform framework for access to real time and historical data and events. This project was supported by TEKES (The Finnish Funding Agency for Technology and Innovation). The used rigorous dynamic simulators were Apros 6 (developed by VTT and Fortum Oyj; www.apros.fi) and NAPCON Simulator (developed by Neste Jacobs Oy; www.napconsuite.com). The used MPC technology was NAPCON Controller and the involved database was NAPCON Informer (both developed by Neste Jacobs Oy; www.napconsuite.com).

2 OPC UA COMMUNICATION

Nowadays the industrial information integration and the security requirements have contributed to successful solutions based on OPC UA communication technology. OPC UA is a platform independent IEC communication standard (IEC 62541) based on a server-client architecture with built-in security in communication. The scalable communication and the customizable information model of OPC UA enable integration all the way from basic automation to management level systems in a relatively straightforward way. Furthermore, OPC UA is an extendable specification comprising of a large amount of domain specific additive systems, e.g., analyzer devices integration. In all, OPC UA is scalable, future-proof and deployed easily [1].

All communication between the two simulators and the APC is handled via NAPCON Informer. NAPCON Informer implements both an OPC UA server and a client which communicate with the OPC UA server of Apros 6 and the OPC UA clients of NAPCON Simulator and Controller. The OPC UA interface is used for both data exchange and simulation synchronization between the tools.

3 CO-SIMULATION WITH APC

There are plenty of rigorous dynamic simulators available on the market today, which are often more or less specific on certain kind of production processes like hydrocarbon processes, pulp and paper processes, power plants, food industry etc. Also special scientific knowledge and specialized engineering resources are strongly involved in each dynamic simulator type. Therefore it sometimes takes too much effort to expand a certain simulator to a totally new application area within a short time. Instead of expanding the verified, "field proven", application area within one simulator environment, it is useful to utilize OPC UA communication between different kind of simulators and to realize co-simulation when combining separate process units with separate process knowledge into a plant wide model. Also via OPC UA communication the co-simulation with the actual process in real time through a DCS (distributed control system) is possible, which makes it possible also to generate look-ahead simulation connected to operator personnel training based on the real process state and history.

Efforts-demanding situations may also rise when dealing with different kind of APC/MPC systems. Oil refining and petrochemical plants have used MPC for decades in a routine way. Usually the plant personnel have become accustomed to only one particular MPC technology, which has managed to land to the plant by committing also the final operation personnel. But within company fusions or when combining, e.g., hydrocarbon processes with chemical, energy production or utility plants can bring together different kind of existing MPC technologies in common operation or to be handled by an overall Dynamic Real Time Optimization (DRTO) system. On the other hand, there may be requirements on more or less tailored MPC applications, e.g., for reactor controls and more general and flexible MPC control technologies, e.g., for distillation controls. In both of these cases OPC UA communication would certainly give an easy way to reach the overall optimal operability despite of separate MPC technologies with separately specialized operation personnel.

3.1 Used Rigorous Dynamic Simulators

Two different rigorous dynamic simulators from totally different industrial process areas were used in this project.

Apros 6 is a multi-functional software for modeling and dynamic simulation of various processes. The main application areas of Apros 6 are power plants (nuclear, combustion and solar) and pulp and paper mills. Apros 6 is a new generation of the software extending especially the functionality of the user interface and support for the modeler's work. Apros installations can be found in 26 countries to simulate the whole process plants or part of it.

NAPCON Simulator includes rigorous properties and dynamic unit operation models having extensive chemical component library with built-in thermodynamics. It is also highly customizable and expandable. It has reliable connection with real DCS/SIS or comprehensive emulated automation system having therefore wide-ranging training and knowledge management facilities. Further there are also full-integrated tools for dynamic control and safety system design and analysis. The main application area of NAPCON Simulator is the hydrocarbon industry as a whole.

3.2 APC Development Environment with NAPCON Controller

The co-simulation of Apros 6 and NAPCON Simulator is connected to NAPCON Controller through NAPCON Informer. All the measurements of the simulators are available for NAPCON Controller which on the other hand manipulates the setpoints of the basic controllers of both simulators.

NAPCON Controller is MPC-based flexible, multi-purpose control technology with effective dynamic process constraint handlings representing both linear and nonlinear multivariable control methods. Development of suitable control modes for simulated process combinations guarantees success in variety of industrial applications. Examples of some necessary MPC features to be verified are [3]:

- Optimal operation near constraints with priority tuning parameters for controlled variables
- The flexibility of partial MPC control modes from application point of view, where individual manipulated variables (MV) and controlled variables (CV) are switched on or off or the switching is done in predesigned groups.
- Handling non-ideal measurements - noise, drift, spikes, quantization, etc.
- Functionality of MPC continuous performance monitoring system using adequate Key Performance Indicators (KPI's). The functionality is possible to verify using the worst practical cases by simulation.

MPC with wide operating range for large dynamical swings and grade changes includes especially economically, but also practically from usability point of view, a challenging limit to be identified by simulation case by case.

4 CASE: REFINERY PROCESS FURNACE

As a case example an oil refinery crude oil furnace is co-simulated with the two rigorous dynamic simulators. Elementarily the furnace has analogies to conventional power plants. In both cases the burning is to be optimized in all circumstances, especially in capacity changes, by keeping the combustion air content in the burners optimal within dynamic constraints and also by keeping the exhaust gas compositions within the set constraints. Based on these requirements the generated MPC application by NAPCON Controller has been verified utilizing the co-simulation via OPC UA communication. Optimal capacity changes of the furnace have been accomplished with the generated MPC system in the co-simulation environment.

4.1 Process Furnace

Process furnaces are the primary energy producers for separation by distillation in oil refineries and petrochemical plants. In accordance with Figure 1 crude oil feed is heated in the process furnace followed by a high fractionation tower (not shown) where the crude oil is separated into different fractions. The desired crude oil feed rate is divided into two parallel coils where the feed is heated first in the convection section and then in the radiation section at the burners of the furnace. Partly evaporated crude oil feed is fed at a desired temperature to the fractionator.

The heating of the furnace occurs by the fuel gas feed rate and the burning is kept optimal by keeping the air feed rate to the burners in accordance with the desired air to fuel gas feed ratio. The burning is monitored by analyzing O_2 - or CO - content of the exhaust gas at the burners. The furnace is kept at a certain pressure by the combustion air pump.

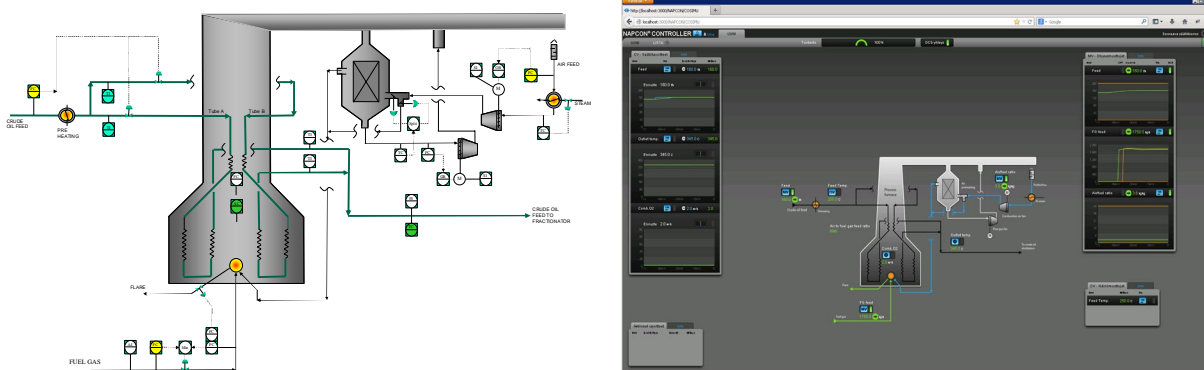


Figure 1. Process furnace flow diagram and the corresponding operator Web display interface.

With fast and relatively slower dynamics the operability of the furnace must response to the requirements of production rate changes and rejection of disturbances of the fractionator and the crude oil feed.

4.2 Furnace Modeling for Co-simulation

Apros 6 modeling covers

- the piping and the combustion of the furnace, including the fuel gas feed with fuel gas quality specifics
- the flow control to the burners,
- the air feed to the burners via the preheater with the flow controller and
- the burning itself with simulated exhaust gas compositions (O_2 , CO , etc.).

The coils are divided into 54 heat transfer sections in the Apros model. The accuracy of the modeling is kept sufficient for operational and environmental investigations and for reliable APC testing.

NAPCON Simulator modeling covers only the crude oil flows including the crude oil specifics through the furnace coils to the fractionator with the crude oil feed controller and the temperature measurements. The accuracy of the crude oil modeling supports the monitoring of the temperature profile and the degree of crude oil vaporizing in the coils and the flashing in the fractionator.

4.3 Model Interfaces and Simulation Control

The interface of the two simulators is the heat transfer surface between the coils and the crude oil in the convection and radiation sections of the furnace. The heat transfer as a phenomenon is stable and deterministic enough for modeling and therefore suitable the verification of OPC UA communication in the co-simulation. At this interface Apros receives from NAPCON Simulator the crude oil temperature. From this, the furnace gas temperature and the heat transfer characteristics of the coils Apros calculates the heat flow which is passed to NAPCON Simulator.

The heat transfer in the coils includes the actual data in the OPC UA communication interface between the two simulators via NAPCON Informer. The two tasks in the co-simulation handled by the OPC UA communication are data exchange between the simulations and the APC and the synchronization of the simulations. For data exchange, the OPC UA Read and Write services are used. For synchronization, OPC UA Methods are applied to implement step-based synchronized parallel simulation execution.

All the measurements of both simulators are available in NAPCON Informer for APC usage. The main measurements for control purposes via OPC UA are the furnace outlet temperature, the oxygen content at the burners and the crude oil feed rate. APC generates control moves via OPC UA to the setpoints of the basic controls of the both simulators; these setpoints are the fuel gas flow rate, the air feed flow rate in Apros 6 and the crude oil feed rate in NAPCON Simulator.

4.4 Process Furnace APC

The scope of multivariable 3 by 3 APC application consists of the following MV's; setpoints of the fuel gas flow rate, the air flow rate and the crude oil feed rate. The CV's with operator given targets are the furnace outlet temperature of crude oil, oxygen content at the burners and the crude oil feed rate to the furnace. As a dynamic constraint of APC is the air to fuel gas feed ratio with an adjustable relief margin. This keeps burning optimal by keeping the combustion air feed rate, relieved by a set margin, above its minimum constraint, which is set by the existing fuel gas feed rate and the set fuel gas feed ratio. All the MV's have their own maximum and minimum hard constraints and delta move maximum and minimum hard constraints.

Crude oil feed temperature is used as a DV (Disturbance Variable) of APC for feedforward control to predict the incoming disturbances.

In the Figure 1 the operator web display interface is presented with all the MV's, CV's, DV's and constraints, whenever they are activated.

5 VERIFYING PLANT CAPACITY CHANGES WITH APC

At grade changes of crude oil and in abnormal situations the furnace feed rate and/or outlet temperature must be changed dramatically to prevent too long off-spec production periods. The worst case can appear, when the fractionator is overloaded and it starts to flood rapidly. In this situation the separation and on-spec production is lost and the manual stabilization of the big fractionator is always time consuming. To predict and prevent the flooding an autonomous heater APC application is needed to rapidly reduce the incoming heat and mass flow rates including optimal control of fast fuel gas combustion and heat transfer. The demand of the control interval approaches DCS control interval.

In Figure 2 a) the crude oil feed rate changes are simulated with APC controls, where the delta moves of crude oil feed are slightly limited and quite loose relief margin in fuel gas to air feed ratio constraint is in use. These constraint settings give quite rapid capacity changes. In Figure 2 b) the furnace outlet temperature changes with APC controls are simulated. In this case tighter relief margin in fuel gas to air feed ratio constraint is used and therefore more constrained and quite stiff temperature responses have been gained.

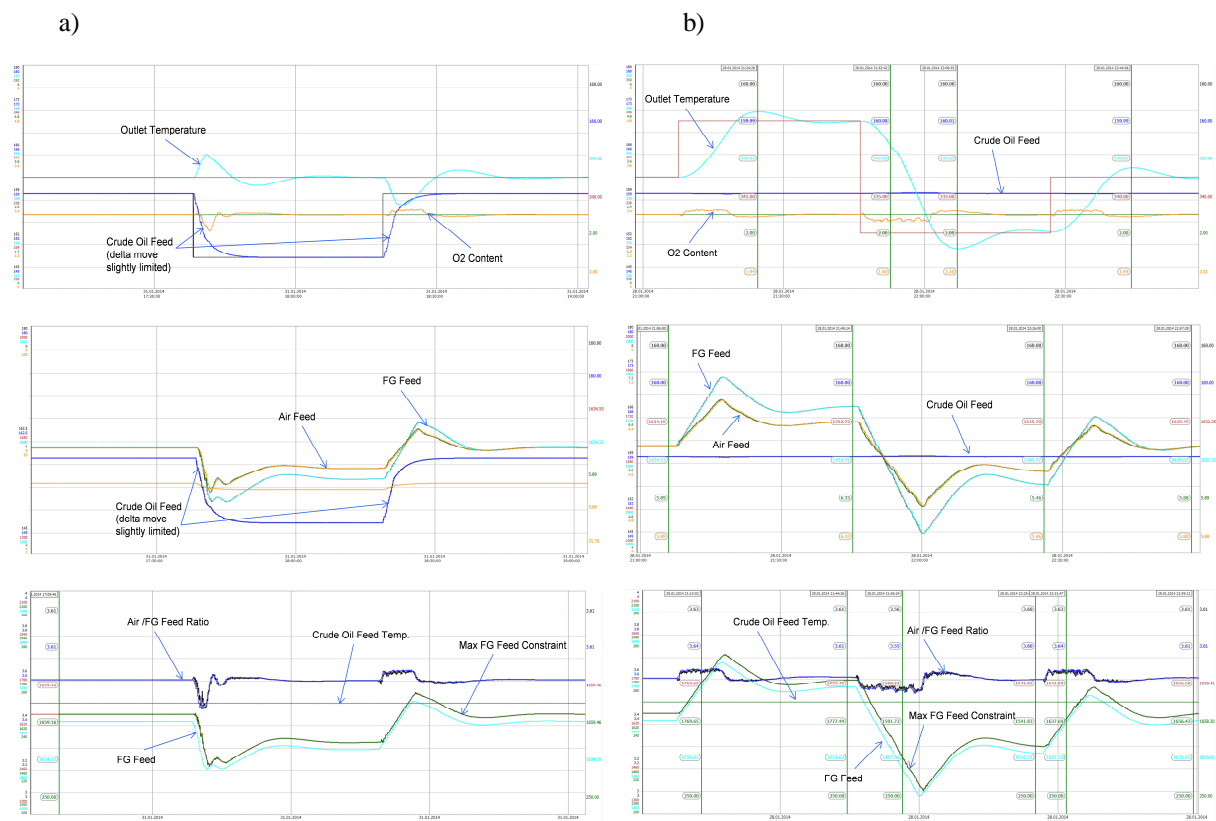


Figure 2. a) crude oil feed changes, b) outlet temperature changes.

6 CONCLUSIONS

Future benefits from this co-simulation environment are as follows:

Final verifications of MPC solutions can be done in co-simulation environment based on the requirements of flexibility in the plant operation without disturbing any real processes. Especially robustness of fully autonomous furnace and power plant MPC solutions can be verified safely also for plant capacity changes.

Similar co-simulation combinations of power plants and hydrocarbon processes with the requirements of flexibility are suitable for future development. E.g. total simulation of combined power plants and exhaust gas treatment units with optimizing MPC can be accomplished. Thereby optimal capacity changes caused by integrated electricity distribution systems can be realized and the requirements of exhaust gas compositions for environmental reasons can be fulfilled.

By connecting simulators via OPC UA communication with real time process through automation systems look-ahead simulation facilities can be easily achieved.

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