

Model-based online applications in the ABB Dynamic Optimization framework

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Keywords: technical calculations, model-based simulation, model tuning, online optimization, model-based control, 800xA, Modelica, HQP

Abstract

ABB Dynamic Optimization is an extension for the control system 800xA. Exploiting the Aspect Objects technology of 800xA, Dynamic Optimization allows the seamless integration of model based applications, such as model-based process control. Running offline and online using one and the same software environment, Dynamic Optimization provides an attractive framework to apply offline results online, in order to optimize the efficiency of an industrial process.

1 Introduction

Industrial plants search for powerful diagnostic and optimization tools to monitor and predict plant performance, issue early warnings for equipment diagnosis, sensor validation and preventive maintenance. New modeling technologies and increasing computational power make the online application of computer simulations more and more attractive.

This paper shows how the Modelica technology is exploited in the Industrial IT Extended Automation System 800xA using the Dynamic Optimization framework.

2 Dynamic Optimization framework

2.1 Industrial IT System 800xA

The architectural framework for the Industrial IT System 800xA is built upon ABB's Aspect Object tech-

nology. Aspect Objects relate plant data and functions – the aspects, to specific plant assets – the objects. Aspect objects represent real objects, such as process units, devices and controllers. Aspects are informational items, such as I/O definitions, engineering drawings, process graphics, reports and trends that are assigned to the objects in the system.

Aspect Objects are organized in hierarchical structures that represent different views of the plant, such as Functional Structure and Location Structure. One object may be placed multiple times in different structures. The idea of placing the same object in multiple structures is based on the IEC standard 1346 [7, 2].

2.2 Dynamic Optimization architecture

Figure 1 gives an overview about the software architecture. Many existing software interfaces and components that are intended for process control are re-used by Dynamic Optimization for model-based applications. These are in particular the connectivity to a process and the treatment of trend&history data using OPC DA and OPC HDA technology, respectively. Furthermore, these are operator graphics, alarms and events, as well as a common configuration database.

Dynamic Optimization adds new software components for the management of model knowledge and for running model-based activities. Model variables are treated like process signals by allocating OPC properties in a simulation server.

The models are being built and tested with a modeling application such as Dymola or MathModelica. Afterwards executable model code is exported to Dynamic Optimization. The numerical solver HQP is employed at runtime. HQP combines a large-scale nonlinear optimization solver with ODE and DAE solvers, see e.g. [5].

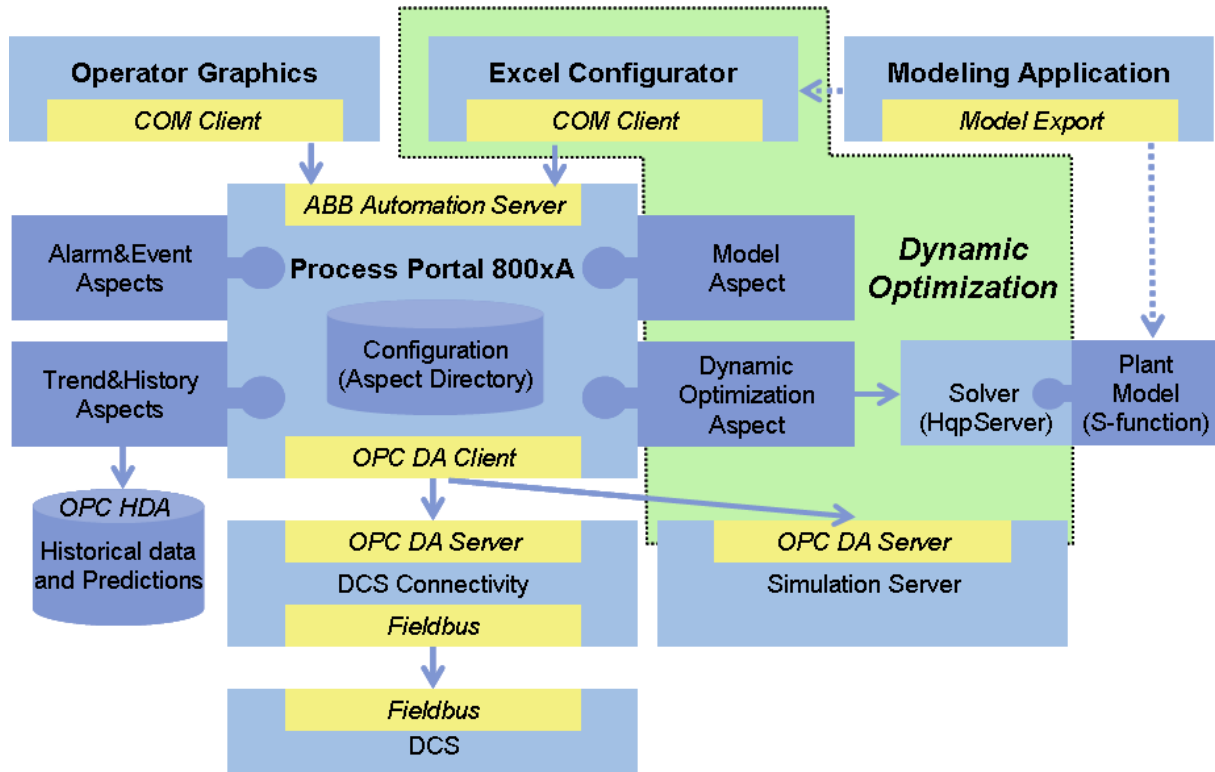


Figure 1: Software architecture of the Dynamic Optimization framework.

Excel serves as intermediate data layer between the modeling application and the control system. This allows to make small changes, e.g. to change parameter values, at runtime. Moreover advanced model based activities, including optimization objectives and constraints not covered by Modelica, can be specified in Excel. Furthermore, an activity can be archived in an Excel file, including the parameterization of the model, solver settings, used process data, and results.

The use of standard interfaces and independent applications for modeling and numerical solution does not only provide for seamless integration re-using existing tools, but it also gives more flexibility regarding the framework itself. This way for instance research studies can be done in a platform more appropriate for research. As the same tools are used, the platform can easily be changed to deploy research results later on.

Take the industrial case study [9] for example. The research on model predictive control of batch processes has been done using Matlab and Simulink as platform, together with the HQP numerical solver and OPC process interfaces [9]. Using Dynamic Optimization, the research results can be deployed in the control system 800xA by running the same model code and using the same solver.

2.3 Introductory example

Consider one wants to perform a simple calculation online, like the determination of the efficiency of a preheater in a power plant. According to water-tube boilers standards [4], the efficiency of a heat exchanger is defined as

$$\eta = \frac{T_{22} - T_{21}}{T_{11} - T_{21}} \quad (1)$$

with T_{11} and T_{21} the inlet temperatures at primary and secondary side, respectively, and T_{22} the outlet temperature at the secondary side.

The heat exchanged in a preheater mostly results from the condensation of the fluid at the primary side. This is why the inlet temperature T_{11} is not used directly from a measurement. It is replaced by the saturation temperature $T_{\text{sat}}(p_{11})$ for a measured pressure p_{11} at the primary side. This gives a more reliable value for the preheater efficiency.

The calculation can be set up graphically in a Modelica tool, see Figure 2. The block heatExchangerEfficiency contains the general calculation given in (1). The saturation temperature $T_{\text{sat}}(p_{11})$ is calculated for a measured p_{11} using a function available in the standard Modelica.Media library.

In order to run the calculation in the control system 800xA, first appropriate Aspect Objects have to set

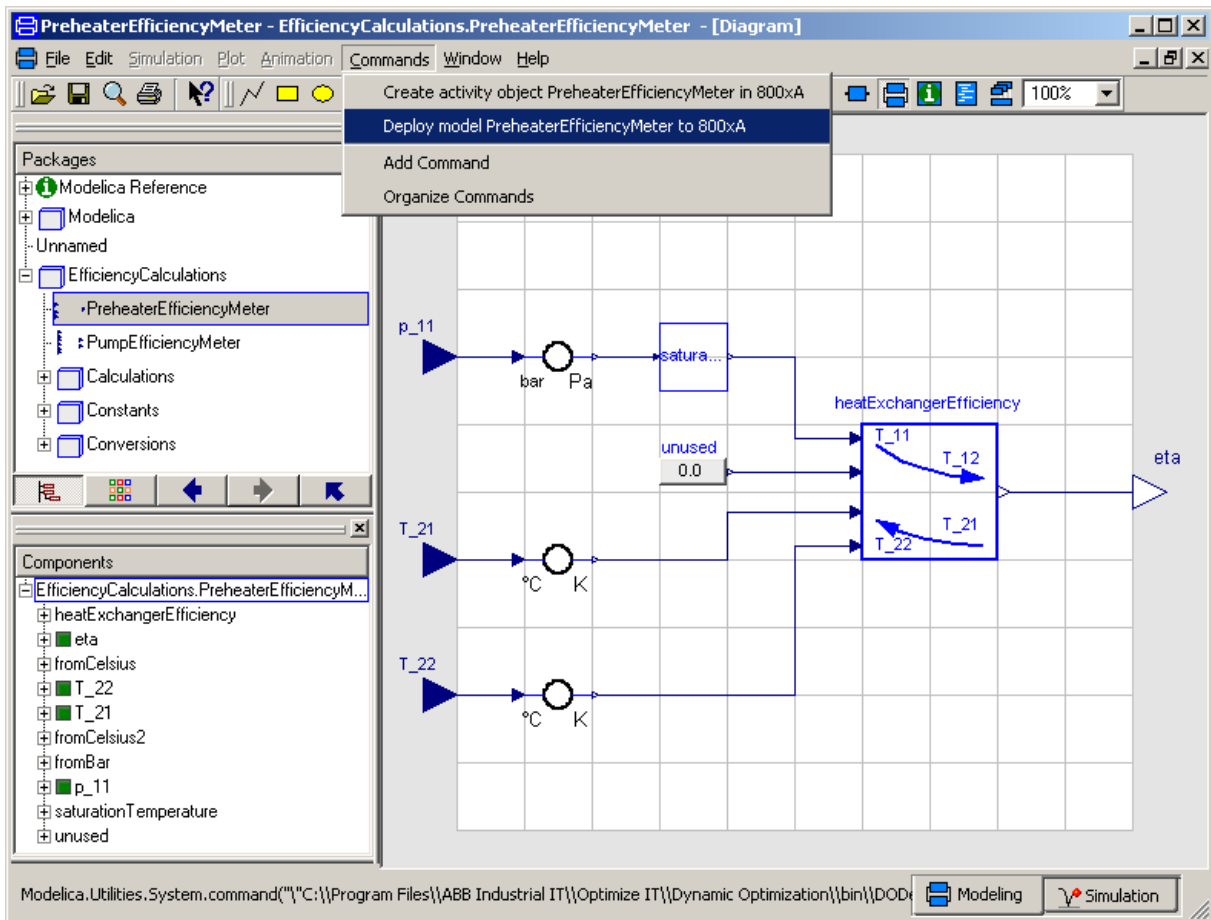


Figure 2: Graphical implementation of a preheater efficiency calculation in Dymola.

The screenshot shows the 'Plant Explorer Workplace' for the 'PreheaterEfficiencyMeter' model. The 'Aspects of PreheaterEfficiencyMeter' table is displayed below.

Aspects of 'PreheaterEfficiencyMeter'	Modified	Desc...	Inherited	Category name
Control Connection	8/15/2007 3:36:3...	Holds...	False	OPC Control Co...
Dynamic Calculation	10/19/2007 12:5...	Aspe...	False	Dynamic Calcul...
Dynamic Calculation Type Reference	10/19/2007 12:5...		False	Dynamic Calcul...
Functional Structure	10/19/2007 12:2...	[Fun...	False	Functional Stru...
Modelica Model	8/15/2007 4:00:0...	Aspe...	False	Modelica Model
Name	8/15/2007 3:36:3...	The ...	False	Name
Object Icon	10/19/2007 12:2...	Icon ...	True	Object Icon

Category	Name	Value	Unit	Ref'd Object	Ref'd Aspect	Ref'd Proper	Description
parameter	heatExchange	1					Relate efficiency to
parameter	heatExchange	-1					Gain of upper input
parameter	heatExchange	1					Gain of lower input
parameter	heatExchange	1					Gain of upper input
parameter	heatExchange	-1					Gain of lower input
parameter	heatExchange	1					Gain of upper input
parameter	heatExchange	-1					Gain of lower input
output	eta	0	1				efficiency of prehe
input	T_22	140	degC				Outlet temperature
input	T_21	110	degC				Inlet temperature at
input	p_11	5	bar				Pressure at primary

Figure 3: PreheaterEfficiencyMeter in 800xA Plant Explorer Workplace.

up. They can be created from the modeling application Dymola by invoking the menu command “Create aspect object PreheaterEfficiencyMeter in 800xA”. The menu command is included as annotation in the model, being accessible from Dymola and calling the according system command provided by Dynamic Optimization. The hierarchical structure of Aspect Objects in 800xA corresponds to the package structure in Modelica, see Figures 2 and 3.

The model can be deployed with the menu command “Deploy model PreheaterEfficiencyMeter to 800xA”. The deployment process consists of multiple steps that have been automated. First the model is translated and an executable dynamic link library is created. Three aspects are configured in 800xA for the Aspect Object PreheaterEfficiencyMeter, see Figure 3 and the relation to the software architecture shown in Figure 1:

1. The Modelica Model aspect declares the interface of the model through inputs, outputs, parameters and states. Moreover the model aspect contains attributes like value, unit and description for each model variable. The empty columns “Ref’d Object”, “Ref’d Aspect”, “Ref’d Property” can be used to link model variables to signals in the control system.
2. The Control Connection aspect declares OPC properties for the model variables, which are served by the Simulation Server.
3. The Dynamic Calculation aspect links the model to the solver and defines solver settings like sampling rate for the calculation.

Besides the aspects, also the Simulation Server for OPC properties introduced by the model and the Dynamic Optimization Service running HQP solver instances are updated during deployment.

3 Model-based applications

The use of Modelica gives access to a broad range of possible applications using a common modeling technology.

3.1 Technical calculations

Many calculations that are of interest for industrial applications have been standardized. The water-tube boilers standards are an example [4]. The standardized formulae and algorithms can be implemented in Modelica and evaluated online. This provides e.g. for the

online determination of thermal stress and the implementation of lifetime counters for critical components of a power plant. Further applications cover the online determination of the plant efficiency.

Such technical calculations are normally set up to run automatically on a specified sample time interval. The results of the calculations are added as new signals to the control system.

3.2 Model-based simulation

Modelica is designed to allow convenient, component-oriented modeling of complex physical systems. Available model libraries significantly simplify the object-oriented modeling process. Such models can run online to analyze and optimize the modeled process. Further applications of model-based simulation include the training of plant operators and the validation of automatic controllers.

Take soot blowing, a cleaning mechanism for steam boilers, as example. Due to constant fouling, the heat transfer coefficient in superheaters and the steam pressure decrease during the operation of a recovery boiler. Soot blowing is applied to clean the boiler.

The modeling and simulation study [8] describes the dynamic modeling of a recovery boiler of a paper mill in Modelica, in order to simulate the effects of fouling and soot blowing on drum pressure and heat transfer coefficients.

3.3 Estimation and optimization

Prior to an online application, a model normally needs to be tuned. Unknown model parameters, such as heat transfer coefficients, need to be estimated based on process data resulting from experiments. This can be done using a Dynamic Estimation aspect. The experiment data is directly available in 800xA through history Log Configuration aspects. The estimation setup can be archived together with the used process data, solver settings and estimation results in an Excel file. Moreover estimation can be configured to run online, in order to analyze the process or to validate measurements. Future development may involve addition of model validation against separate data sets as well as adding grey-box calibration methods similar to the ones described in [1].

Having a well tuned model, it can be used to optimize the modeled process, such as the optimization of steady-state setpoints or of transient control trajectories. The Dynamic Optimization aspect allows to setup and solve optimization problems for a given model.

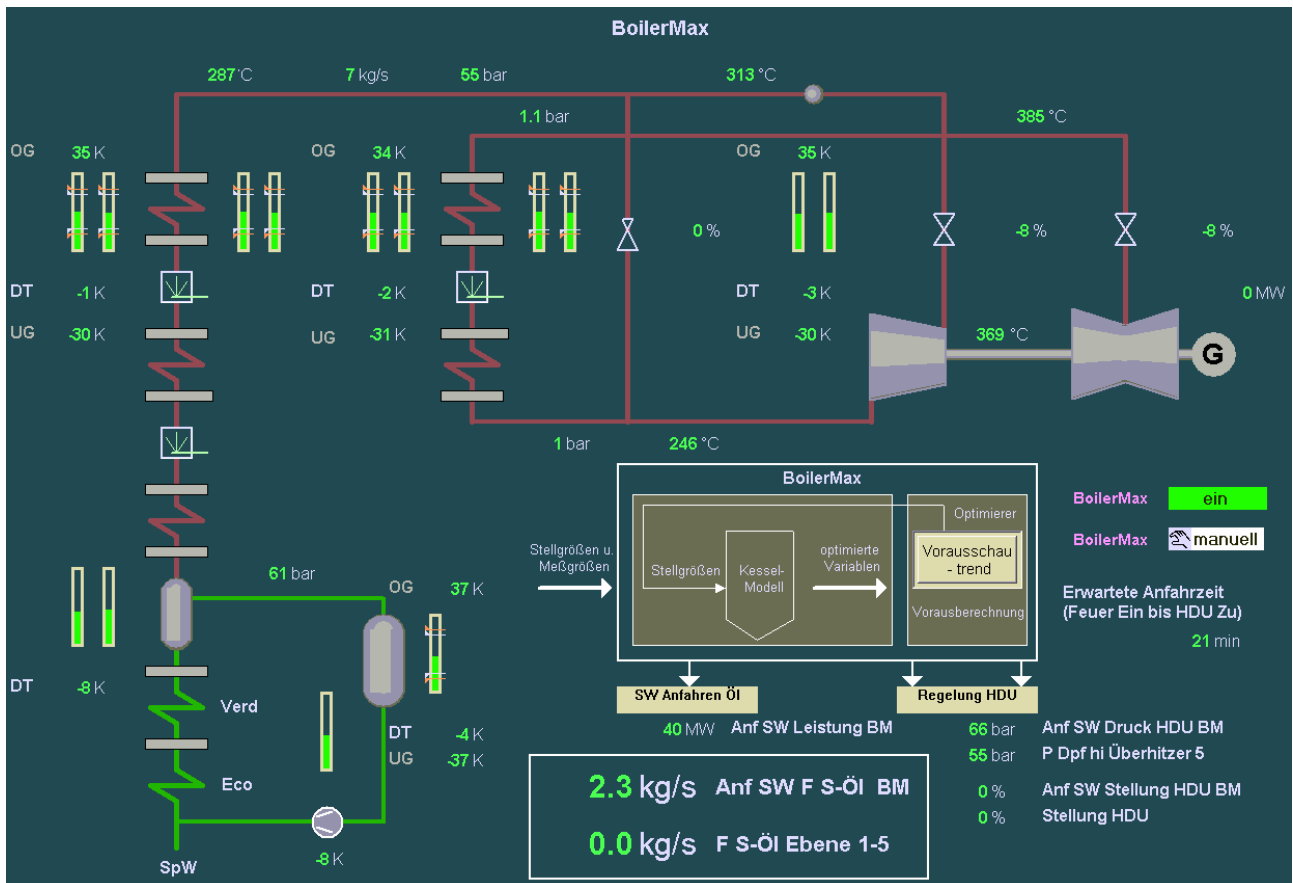


Figure 4: Operator display for boiler startup optimization.

The solver HQP covers initial-value simulation problems for hybrid DAEs resulting from the translation of a Modelica model. Mathematical optimization and estimation problems, however, can currently only be solved for a simplified hybrid DAE, containing no state events. A formulation and solution of mixed-integer nonlinear optimization problems, as required for instance for planning&scheduling of production processes, may be subject of future development.

3.4 Model-based control

Applying Model Predictive Control (MPC) technology, a model can be used to predict the optimal operation of the process. The calculated predictions get applied in closed control loop. An example application, that has been installed successfully in several power plants, is the startup optimization of large steam boilers [6, 5]. Appropriate process models can be built based on the Modelica.Media and Modelica.Fluid libraries [3].

Figure 4 shows an operator display used for boiler startup optimization. Elements known from a regular

operator graphics, such as temperature measurements and operator controls, are seamlessly integrated with new elements resulting from the model based BoilerMax application, such as thermal stress values, stress limits and predicted startup time. Furthermore, the results of the predictive startup optimization are accessible in a regular trend display showing the optimization results as future process data.

3.5 Runtime scheduling and supervision

Individual model based activities can be performed for a specified sample time or triggered by changing process data on-line. However, more advanced runtime scheduling might be required for complex activities. For instance, one might want to synchronize multiple activities, supervise solver times and implement specific error recovery strategies. Such advanced runtime scheduling can be formulated in Modelica as state graph [10]. In the Dynamic Optimization framework, a runtime scheduler is running as additional activity, triggering and supervising other activities, such as state estimation and predictive optimization.

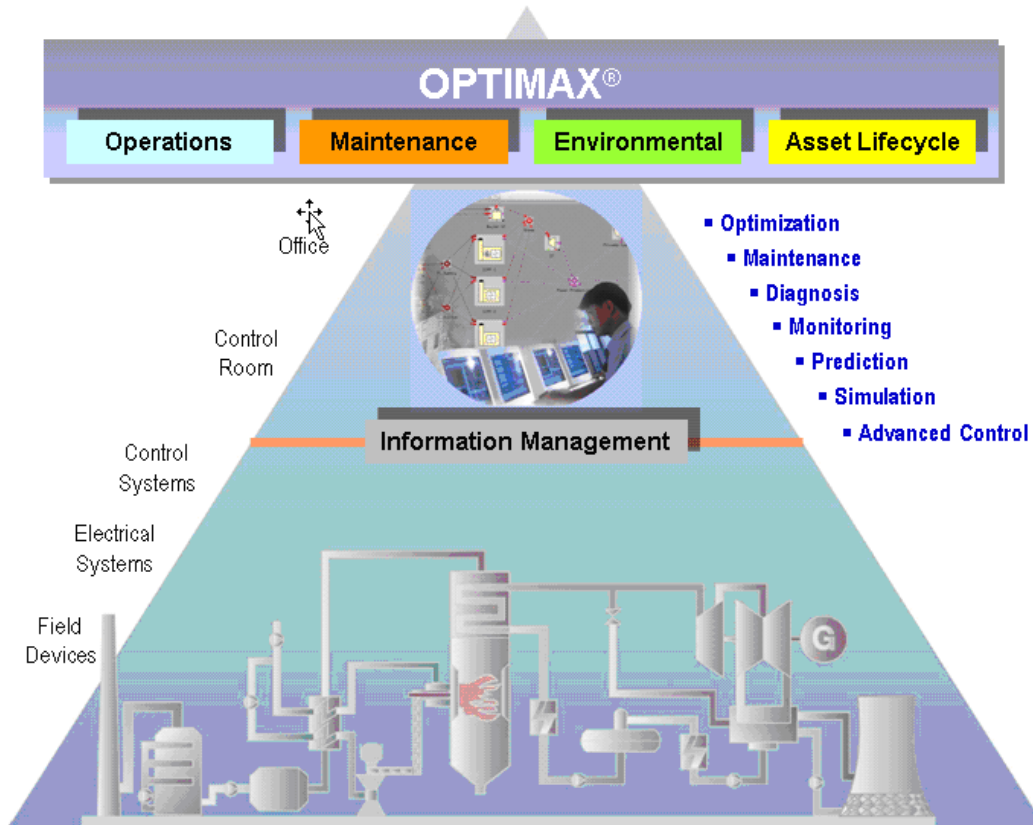


Figure 5: Overview about the ABB solution OPTIMAX®.

4 Optimizing energy efficiency in the power industry

The primary key to energy efficiency in the power industry is reducing the cost of fuel and consumables. Industrial plants are huge energy consumers; therefore small percentage savings can have a significant impact on their bottom line. Figure 5 gives an overview about the ABB solution OPTIMAX®, which uses Dynamic Optimization as one tool, besides others.

4.1 Maximize operational performance & efficiency

OPTIMAX® operations solutions can handle utilities with complex generation portfolios which are seeking to minimize energy generation costs, be it electrical or a combination of electrical and other forms of energy. In addition, deciding whether or not it makes sense to buy or sell power or fuel, start or stop a unit, save lifetime, or postpone a preventive maintenance outage can be easily answered.

4.2 Minimize maintenance cost

Maintenance expenses are second only to fuel costs as variable costs. The key to optimizing assets is often having information that is accurate, timely and actionable. Clearly, the ability to act on reliable information is as essential as having access to the information in the first place.

Work preparation and planned condition-based maintenance are increasingly important for reduction of downtime. The benefit of OPTIMAX® Maintenance Management Solutions is to achieve and maintain a high level of availability, quality and safety of the plant. This applies to current plant operation but is particularly valid for inspection, overhaul and service activities. For industrial users this leads to a higher Return On Asset (ROA) which is a key driver of shareholder value.

4.3 Reduce emissions & waste

The measurement and reduction of hazardous emissions is increasing in importance and regulatory standards are getting stricter every day. Emission of green-

house gases now has measurable economic value and operators have a real incentive to lower these emissions. The OPTIMAX[®] environmental solutions reduce emissions by monitoring flame quality, measuring coal flow and carbon in ash content, and providing Advanced Process Control (APC) which optimizes combustion, shortens boiler startup times and improves efficiency.

4.4 Extend the Asset Life Cycle

From an economic perspective, plant managers seek to balance their investment in new assets against performance, risk and downtime. OPTIMAX[®] solutions for lifecycle optimization of assets are able to schedule the most economical operation of different generating units and trade-off income from sales against lifecycle costs. In addition, this approach is also capable of taking emission costs into account, i.e. more stringent CO₂ requirements may make plants that are still mechanically functional uneconomic to run. The advantage of these decision support tools is the ability to include plant ageing models to find the optimal operational strategy between maintenance outages, especially when operating under environmental constraints.

5 Conclusions

The Dynamic Optimization framework allows running model-based applications in the Industrial IT Extended Automation System 800xA. The Modelica technology and the Aspect Object technology of System 800xA are integrated seamlessly. Dynamic Optimization provides software components that establish links between industrial control and the world of physical modeling and simulation.

Simple model based simulations can be deployed directly from a graphical modeling application, such as Dymola or MathModelica. Excel is used as intermediate data layer. This allows the treatment of advanced solver settings, such as optimization constraints, and of process data used for offline applications, such as experiment data used for parameter estimation.

A broad range of model-based applications is becoming possible. Examples are the simulation of recovery boilers in pulp mills [8], model predictive control of batch processes [9], and cost optimal startup of power plants [5].

The optimization of energy efficiency is a particular application area of high interest.

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