Starting the boiler

Startup optimization for steam boilers in E.ON power plants

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There is a proverb saying that a watched pot never boils. When it comes to bigger pots however – such as boilers in power plants – looking away is certainly not the best control strategy in starting them up.

Optimization efforts in power plants often focus on extracting as much usable energy out of the fuel as possible during normal operation.

There is another important way to improve efficiency, however, and this lies in optimizing startup procedures. This is all the more important as the fuel used at start-up is often of higher grade and more costly than that used in normal operation.

BoilerMax is a predictive controller used to minimize start-up costs. Besides fuel costs, it takes into account such constraints as maximum permissible loads of critical components and flow rates.

In the course of the last two years, BoilerMax has been installed in several power plants of the energy company, E.ON where it has typically achieved savings of 10 to 20 percent of the costs for fuel and auxiliary power required for a startup.

Extraction and generation

Over the last two years, BoilerMax has been installed in several E.ON power plants and integrated with several control systems. In the 622 MW Staudinger 4 gas-fired unit [1] and in the 900 MW Heyden 4 coal-fired unit, it works with a Procontrol P unit control system. In the 420 MW Ingolstadt 4 oil-fired unit and the 450 MW Zolling 5 coal-fired unit, BoilerMax has been integrated into a new 800xA control system, installed in the course of a turbine retrofit project.

The operating principle of BoilerMax

BoilerMax especially takes into account fuel costs and thermal stress in critical thick-walled components and uses this data to compute optimal setpoints for the fuel supply and the operation of the high pressure (HP) bypass station (the high pressure turbine can be bypassed in the steam circuit during startup to permit a faster build-up of boiler pressure).

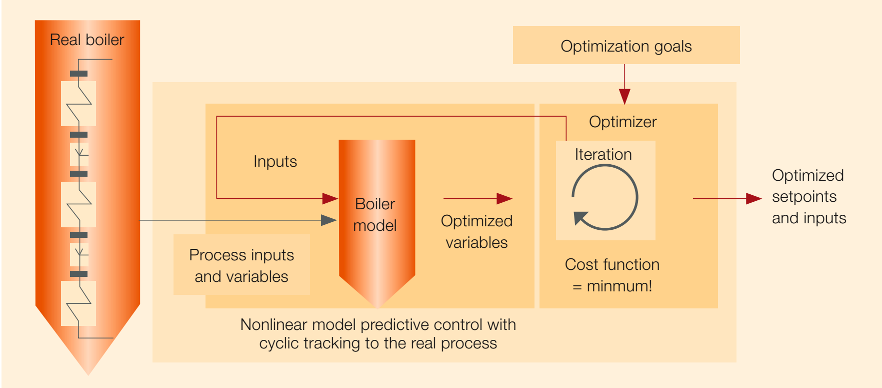
The functional principle of BoilerMax is shown in 1. Measured values are used to calibrate a physical unit model. Based on this nonlinear model, BoilerMax optimizes the remainder of the startup procedure. The resulting startup curves computed on-line are then integrated into the existing unit control concept, where they are used as correction setpoints.

BoilerMax's prediction horizon is 60 to 90 minutes, covering the entire duration of the boiler startup – up to the point where the turbine is rolled on steam. This way, the most cost-efficient overall operating mode can be computed. The predicted data is updated every one to two minutes, enabling an adequate response to disturbance conditions.

The startup costs to be minimized are in the area of fuel, auxiliary power and auxiliary steam, from "fire on" to "generator on-line" or "HP-bypass closed."

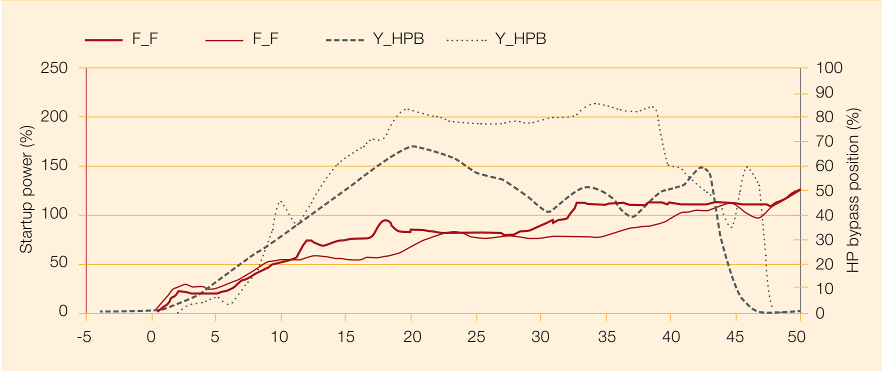
Independently of the cost savings realized, the model-based multi-variable controller also enables a predictive integration of thermal stress data into the closed control loop. The level of flexibility, eg, covering different

1 Functional principle of BoilerMax

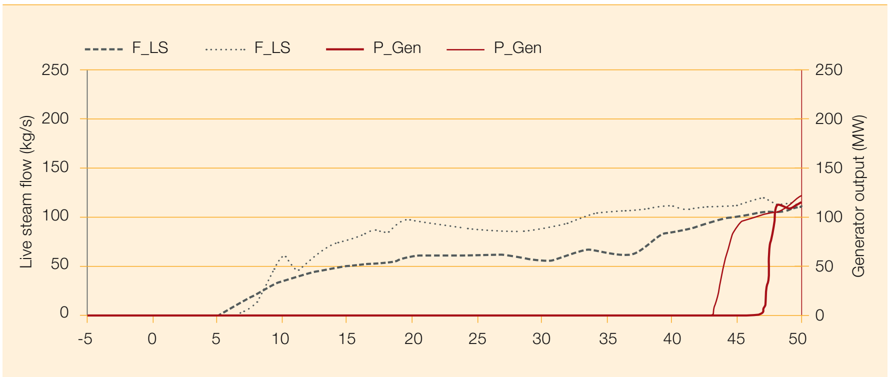


2 Comparison of two startups with BoilerMax (bold lines) and without BoilerMax (thin lines) in the Ingolstadt oil-fired power plant, unit 4

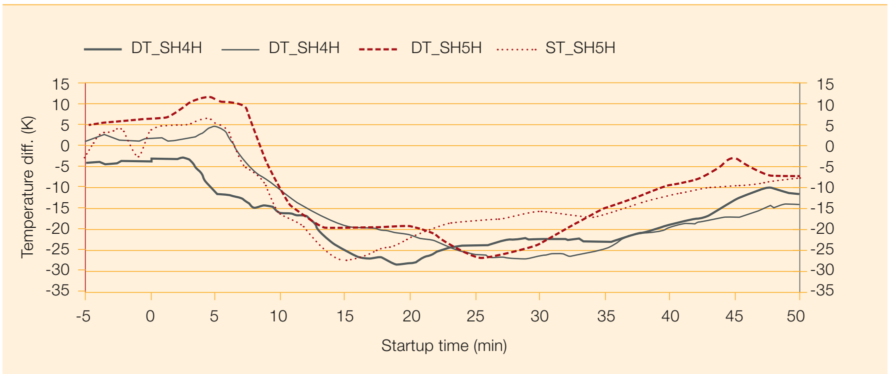
a Fuel quantity (F_F) and the HP bypass position (Y_HPB)



b Live steam flow (F_LS) and the generator output (P_Gen)



c Temperature differentials (DT_SH4H) and (DT_SH5H) occurring in HP headers of the two last superheater levels



downtimes, is improved as the physical model is continually adjusted to match the current state of the plant. Moreover, the startup can be adapted to changes in basic conditions, such as different fuel costs or maximum permissible loads, by modifying the target function and optimization constraints, respectively.

Operational experience

Reducing fuel consumption

Thanks to the predictive startup optimization, it is often possible to run a startup using less fuel, while maintaining the usual startup time and stress loading on critical thick-walled components. 2 shows a comparison of two startup procedures in Ingolstadt power plant's unit 4. The diagrams clearly show that it was possible to run a similar boiler startup while realizing an approximate 20 percent reduction of fuel consumption. Such fuel savings are possible because the steam flow used for starting-up can be decreased by simultaneous and coordinated reduction of the opening of the HP bypass station. In addition, the startup time is slightly reduced.

BoilerMax takes into account fuel costs and thermal stress in critical thick-walled components and uses this data to compute optimal setpoints.

With a higher level of automation, achieved by the optimized startup procedures, startup procedures generally become more consistent. 3 represents the startup costs as a function of the duration of the preceding standstill. The spread of startup costs is most visibly reduced in the case of frequent brief standstills, with numerous startup runs taking place under similar conditions. The optimized startup costs achieved with BoilerMax are at the lower end of the cost range that is characteristic of operations without BoilerMax. On average, the startup optimization resulted in a 19 percent reduction of the startup costs.

Following brief standstills, startup costs are high because of the high live-steam temperature that has to be built up on account of the high initial temperature in the turbine. Startup costs also rise after long standstills, however, because of the lower starting temperature of the boiler.

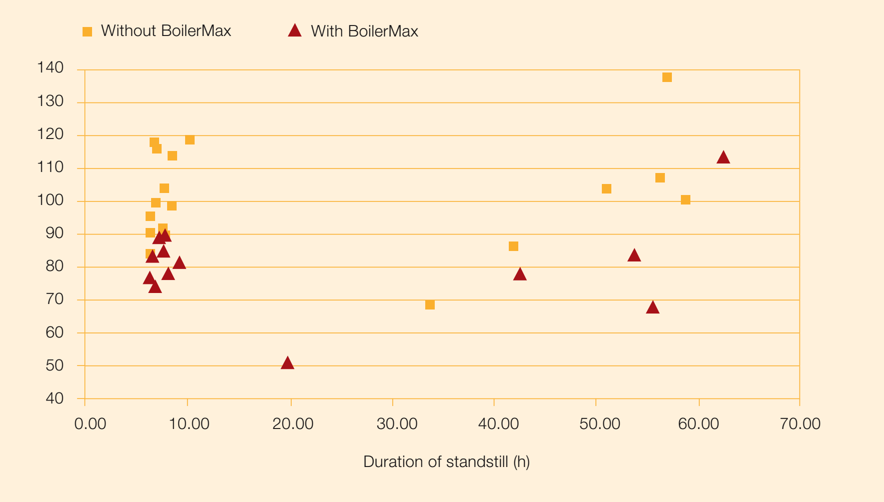
The reduction in fuel consumption resulting from Boilermax's optimization, as well as lower steam production and, in some cases, a slower pressure build-up, may give operators the impression that the entire startup procedure is somehow dragging on. However, it is important to consider that, during boiler startup, the target setpoints for steam flow and pressure must be attained only when the turbine is actually about to be rolled on steam. The predictive optimization concept makes full use of this fact.

The startup times achieved in Unit 4 of the Staudinger power plant are shown in 4. These curves show that BoilerMax did not prolong startup times.

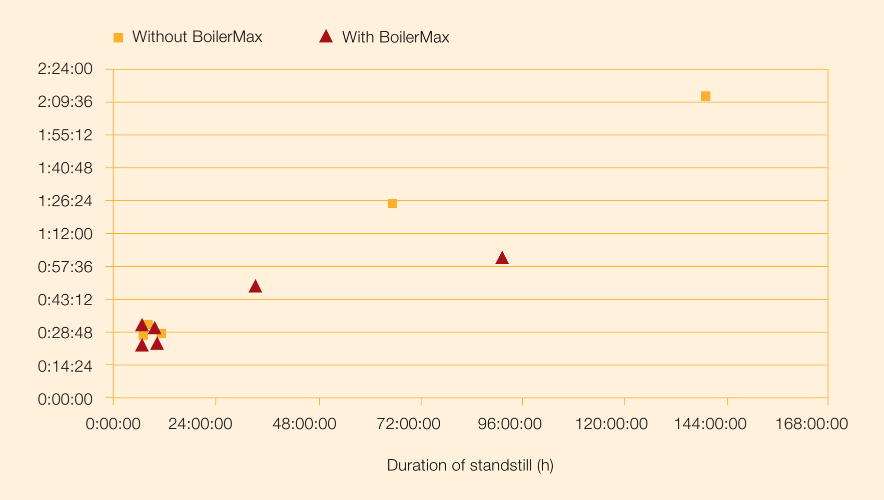
Reducing startup times

The startup times can generally be reduced if an intensification of the heat-up process is admissible and higher heat-up stress is acceptable. Applying predictive startup optimization in order to reduce startup times is advisable if the permissible heat-up stress

3 Startup costs as a function of the duration of the standstill in the Ingolstadt oil-fired power plant, unit 4, with and without BoilerMax



4 Startup times as a function of the standstills in the Staudinger 4 gas-fired unit, indicated for ten startups over a period of one month



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margin is not fully exploited, or if the load is distributed unevenly during startup.

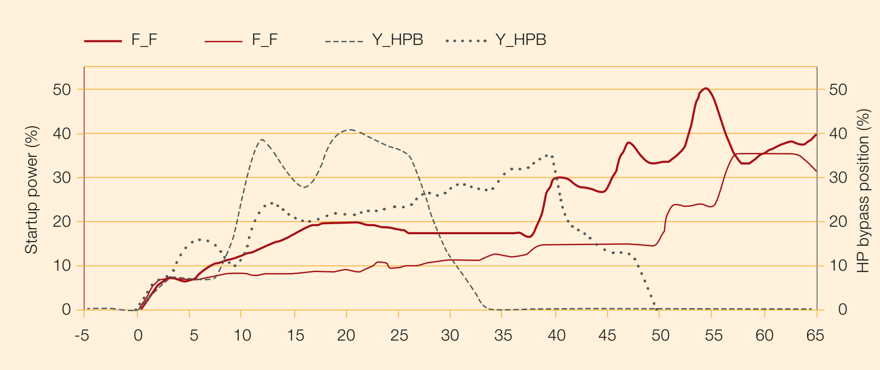
A comparison of two startup procedures in the Zolling coal-fired power plant is shown in 5. Without BoilerMax, the margins for heat-up stress were not fully exploited before the 48th minute. The maximum temperature differential in the HP outlet headers was about 20 K, whereas the admissible limit was about 30 K.

Only during subsequent loading of the turbine, was the maximum heat-up stress reached at around minute 60.

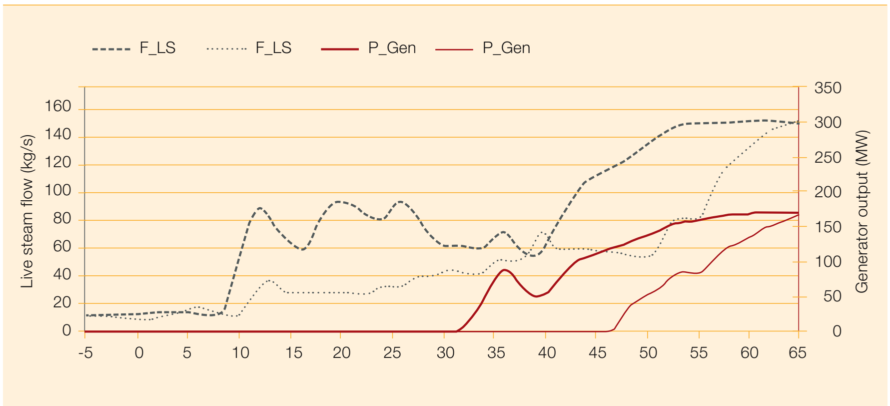
The ΔT limit used by BoilerMax is a function of the pressure which is generally specified by the boiler supplier. As an option, the limits can be recalculated during the physical modeling of the boiler and agreed in consultation with the power plant owner.

5 Comparison of two startup procedures with BoilerMax (bold lines) and without BoilerMax (thin lines) in the Zolling coal-fired power plant

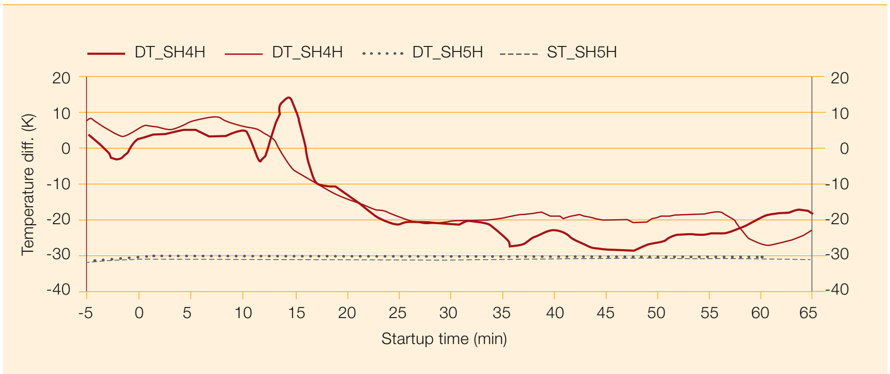
a Fuel quantity (F_F) and the HP bypass position (Y_HPB)



b Live steam flow (F_LS) and the generator output (P_Gen)



c Temperature differentials (DT_SH5H) [K] as well as the associated limit values (DT_SH5H_min) [K] occurring in the HP outlet headers



As shown in 5, predictive startup permitted a better utilization of the margin as early as minute 35. This was achieved by increasing the fuel supply at a higher rate from the beginning, while at the same time opening the HP-bypass station to a greater extent. This reduced the startup time by 33 percent. The amount of heavy fuel oil needed for starting-up was reduced by about 6 percent. Since a shorter startup time is accompanied by a lower demand for auxiliary power (light oil and electrical auxiliary power), the total startup costs were diminished by about 11 percent. Moreover, there is a high savings potential in coal-fired plants when the shift from startup fuel to coal firing can be achieved earlier. To achieve this, it is important to be able to start up using a high overall quantity of fuel.

On average, the startup optimization resulted in a 19 percent reduction of the startup costs.

With predictive startup optimization, the amount of fuel is not necessarily increased monotonically, but can be cut back after an initial excess supply.

Operating and monitoring

The operating screen used in the Zolling plant is shown in 6. The left and the upper parts show the process parameters that are especially relevant during startups. The lower right area is used for the actual BoilerMax application. The setpoint settings for fuel and HP bypass control, as computed by BoilerMax, are shown along with the actual values.

The process values shown in this display primarily cover the live-steam parameters and temperature differentials in thick-walled components. In order to avoid cluttering of the display, the ΔT readings are shown in graphical form (bar charts). Alphanumerical representation is limited to the maximum values for each superheater level and the associated limit values.

Visualizing ΔT limits is especially important, as these values are used by

BoilerMax in a closed control-loop for defining the fuel and HP-bypass control actions. It is therefore important to present information on the current heat-up stress and the available margins so that the operator will be able to correctly understand the setpoints computed by BoilerMax.

With a new 800xA process control system, the predictive data computed on-line during each startup, is available directly at the operator's workplace. Predicted startup data can be viewed in a regular operating trend that represents the values to be expected in the future.

Integration into the unit control system

Predicting and optimizing the startup procedures of a boiler on the basis of a physical model involves elaborate numerical processing. BoilerMax is therefore implemented on a high-performance PC that is linked to the unit control system via a signal interface.

From a software point of view, BoilerMax has been implemented by ABB using the Dynamic Optimization system extension for the company's Industrial IT Extended Automation System 800xA. This assures a high degree of transparency and flexibility regarding its capability of being integrated into the operational instrumentation and control equipment. Two implementation scenarios are shown in 7.

In the first case, the BoilerMax PC can be implemented independently and be connected directly to a control cabinet. Viewing and operating occur through regular operating and monitoring stations. In plants where the operating and monitoring stations are implemented as component parts of the System 800xA, the PC on which BoilerMax is running can be integrated as an application server. This provides a special advantage: all parameter settings and calculation results, including the predicted process values, can be made visible and be integrated into the display without additional effort. Furthermore, this facilitates staff familiarization with the BoilerMax solution and this PC can be included in the regular maintenance routines for the System 800xA.

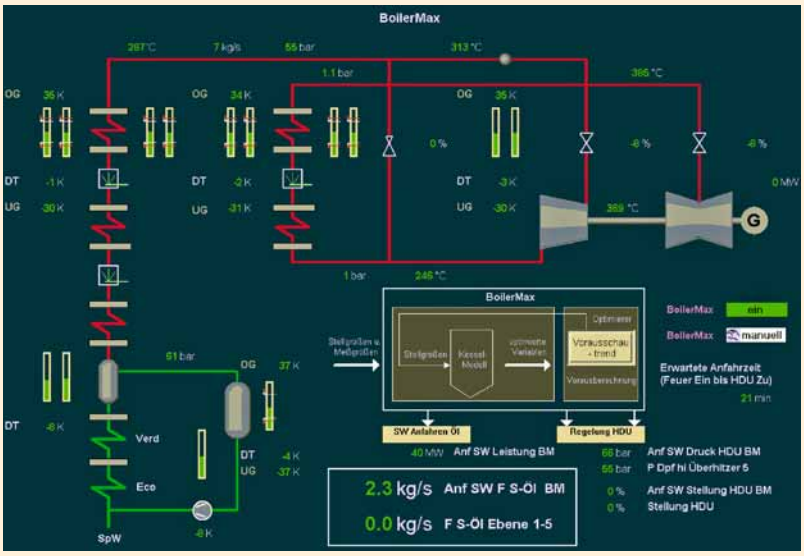
In the Ingolstadt and Zolling power plants, the BoilerMax PC has been integrated with the 800xA operating system which was installed during a turbine retrofit project. In the Staudinger unit 4 and Heyden power plants, the BoilerMax PC is linked to the Procontrol P process control system via a serial interface.

> Predicting and optimizing the startup procedures of a boiler on the basis of a physical model involves elaborate numerical processing.

The unit model used for startup optimization is adjusted on-line by incorporating 100 to 200 measured values. In general, these signals are connected to the process control system as analog signals. As an alternative, a ProfiBus connection has been established between the newly installed turbine controller and the existing unit control system in the Ingolstadt plant. The main advantage of this digital bus coupling is a higher flexibility, because individual signals can additionally be integrated, requiring little extra work. Longer signal transfer times might be viewed as a possible disadvantage; in the Ingolstadt installation, however, no problems arose in this regard. The optimization results are fed back into the control system using approximately ten signals. They are integrated into the existing control concept in the form of setpoint corrections for fuel and HP bypass control.

Depending on the given circumstances, this integration may affect different system levels. In the Zolling power plant, the optimized setpoint for startup fuel supply is only visualized and then applied manually by the operating staff. In Unit 4 of the Staudinger power plant, both fuel and HP bypass control are automatically performed by BoilerMax. At present, however, BoilerMax needs to be activated before each startup. In the Ingolstadt power plant, BoilerMax is activated automatically. The more automated the integration of BoilerMax is, the higher the achievable savings potentials: A sustained improvement of cost-efficiency will ultimately be achieved only by repeated use of the optimization function. A higher degree of automation, however, poses higher demands on the robustness of the startup optimization in view of, eg, automatic detection and handling of disturbances.

6 BoilerMax operating screen used in the Zolling power plant. Because of the high computing power required, BoilerMax is run on a PC that is configured as an application server.



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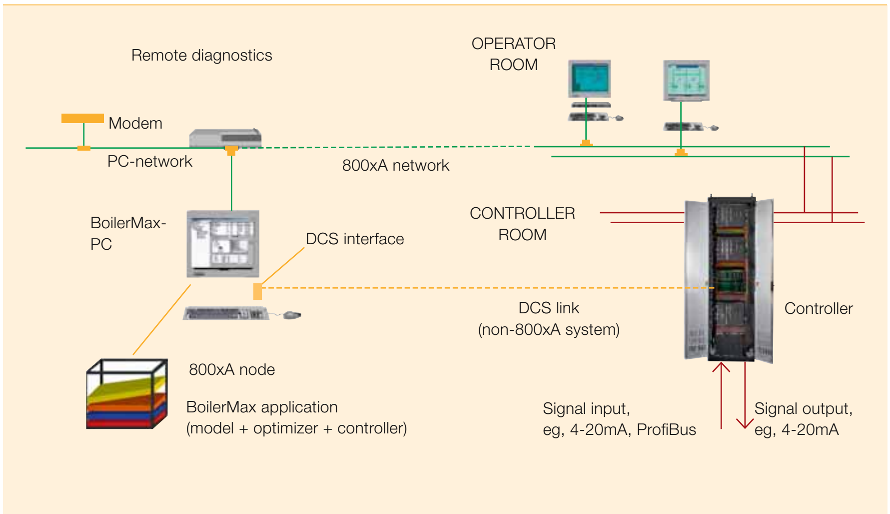
7 Integration of the BoilerMax PC
(Secondary control room, Control room, DCS interface, I&C room, Control cabinet, Optimizer, Controller, Signal input, ProfiBus, Signal output)



The implementation of the online optimization using the Dynamic Optimization system extension provides for openness of the advanced control solution through a high level of integration with the Extended Automation System 800xA [4].

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Successful implementation

The savings realized through online optimization are generally within 10 to 20 percent of the normal costs of fuel and auxiliary power for each power plant startup. The modifications of the startup mode depend on the specific requirements of each power plant.

In the Staudinger unit 4 and Ingolstadt unit 4 power plants, the savings were brought about by a reduction of the fuel consumption and a coordinated lower live steam flow during boiler startup. Both startup times and stress loading of critical thick-walled components remained approximately the same.

BoilerMax was presented at VGB's 2004 congress on "Electrical, Control and Information Technology in Power Plants" together with first practical results from its pilot application in the Weiher III power plant [1]. Results obtained in the Staudinger 4 power plant, where BoilerMax was installed together with a new control system, were presented in [2]. More details about the control and optimization algorithm can be found in [3].

References

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[4] **Franke, R., Babji, B. S., Antoine, M., Isaksson, A.** Model-based online applications in the ABB Dynamic Optimization framework to appear, 6th International Modelica Conference, 2008.