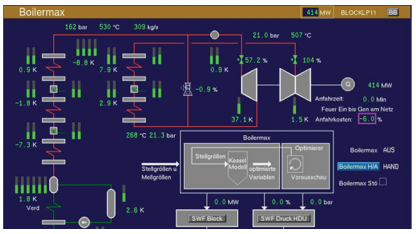
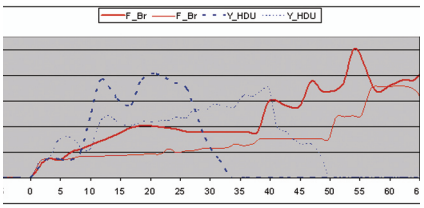
Operational Experience with Startup Optimization for Steam Boilers

E.ON's Staudinger, Heyden, Ingolstadt und Zolling Power Plants





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Starting up economically

BoilerMax is a predictive boiler load-margin computer implementing a nonlinear, model-based multi-variable controller for the purpose of online optimization of boiler startup procedures. This tool is capable of optimizing the fuel costs during startup. The specific basic process conditions, such as thermal stress of critical thick-walled components and the margins for maximum permissible loads are predicted and included in a closed control loop.

Over the last two years, BoilerMax has been installed in several E.ON power plants: in the 622 MW Staudinger 4 gas-fired unit, in the 420 MW Ingolstadt 4 oil-fired unit, in the 450 MW Zolling 5 coal-fired unit and in the 900 MW Heyden 4 coal-fired unit.

Operating and monitoring are done using the regular process control facilities. Independent of the integration solution chosen, the operator will have an operating screen which offers an overview of the most vital startup parameters and of the optimized setpoint settings, as computed by BoilerMax.

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 approximately remained the same, with or without startup optimization.

Startup times can generally be reduced by increasing the loading of critical thick-walled components or by better exploiting the margins through more homogenized loading. In the Zolling coal-fired unit 5, a cost reduction was achieved through improved exploitation of margins and through the resulting shorter startup times. Coal-fired power plants offer high additional savings potentials, provided that it is possible to shift from startup fuel to coal at an earlier point.

Besides the cost savings, the BoilerMax predictive startup optimization tool can improve the reproducibility of startup procedures, thus reducing the spread of characteristic parameters, such as startup costs. The startup procedure is defined on the basis of the respective basic process conditions, e.g. the maximum admissible loading for critical thick-walled components. From such input data, the model-based optimization tool computes optimal setpoints for fuel and HP bypass control. This way, the startup operation can be adapted to changing basic conditions, such as fuel costs and maximum permissible loads, when necessary.

The Operating Principle of BoilerMax

The primary purpose of BoilerMax is to minimize startup costs while taking the given process-specific basic conditions into account. Especially the fuel costs and thermal stress in critical thick-walled components are taken into account when computing the optimal setpoints for the fuel supply and the HP bypass station.

Fig. 1 shows the functional principle of BoilerMax. During a startup procedure, the actual values, which are cyclically scanned for temperatures, pressures and steam mass flow rates, are used for adjusting a physical unit model.

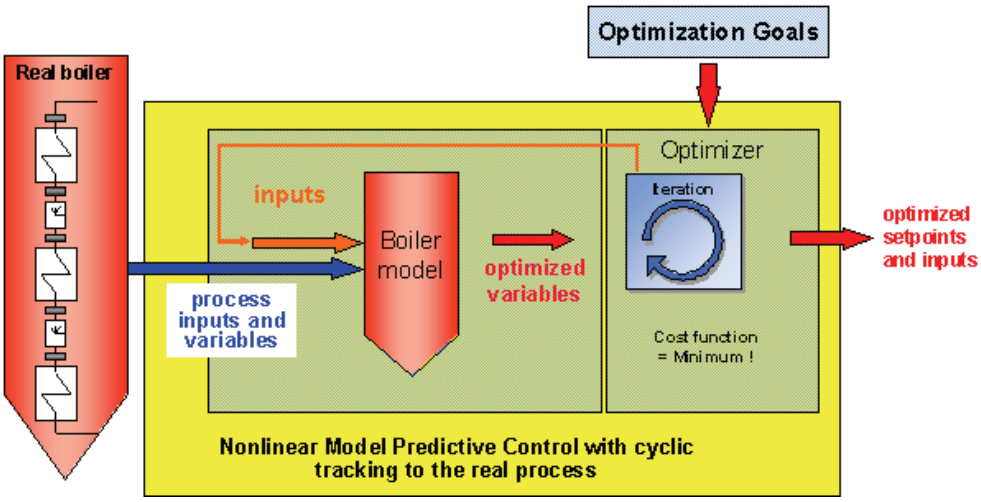

Figure 1.: Functional principle BoilerMax

Based on this nonlinear model, BoilerMax applies its predictive optimization routines to the rest of the startup procedure. The resulting startup curves computed on-line are then integrated into the existing unit control concept, serving as correction setpoints.

The prediction horizon is 60 to 90 minutes, thus covering the entire length of a 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, thus enabling an adequate response to disturbance conditions. Because of the high computing power required, BoilerMax is run on a PC that is configured as an application server.

The startup costs to be minimized refer to fuel, auxiliary power and auxiliary steam costs incurred during a boiler startup, from 'Fire ON' to 'Generator On-Line' or 'HP Bypass Closed'.

Independent 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 – e.g. covering different 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 changing basic conditions, such as different fuel costs or maximum permissible loads, by modifying the target function and optimization constraints, respectively.

Reducing Fuel Consumption

With 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.

Figure 2 shows a comparison of two startup procedures in the Ingolstadt power plant, unit 4. The diagrams clearly show that it was possible to run a similar boiler startup while realizing an approximate 20% reduction of fuel consumption. Such fuel savings are possible, since 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.

With a higher level of automation, achieved by the optimized startup procedures, startup procedures generally become more consistent.

Figure 4 represents the startup costs as a function of the duration of the preceding standstill. In particular, in the case of frequent brief standstills, when numerous startups are run under similar conditions, the spread of startup costs is obviously reduced. 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 significant reduction of the startup costs.

In the case of brief standstills, startup costs are high, as a high live-steam temperature has to be built up, since the temperatures in the turbine are still high. On the other hand, startup costs also rise in the case of long standstills because then the boiler cools down to lower temperatures.

On account of a reduction of fuel consumption, steam production and, in some cases, a slower pressure build-up, the operator might get the impression that the entire startup procedure is somehow dragging on. However, it is important to consider that, during boiler startup, the target setpoints needed for steam flow and pressure must be available only when the turbine is about to be rolled on steam and that the predictive optimization concept makes full use of this fact.

Reducing Startup Times

The startup times can generally be reduced if intensifying the heat-up process is admissible and higher heat-up stress is acceptable. Applying predictive startup optimization in order to reduce the startup time is advisable if the permissible heat-up stress margin is not fully exploited, or if the load is distributed unevenly during startup.

Figure 3 shows a comparison of two startup procedures in the Zolling coal-fired power plant. When starting-up without BoilerMax, the margins for heat-up stress were not used before the 48th minute. The maximum temperature differential in the HP outlet headers was approx. -20 K, whereas the admissible limit was approx. -30 K. Only during subsequent loading of the turbine, the maximum heat-up stress was reached around minute 60.

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

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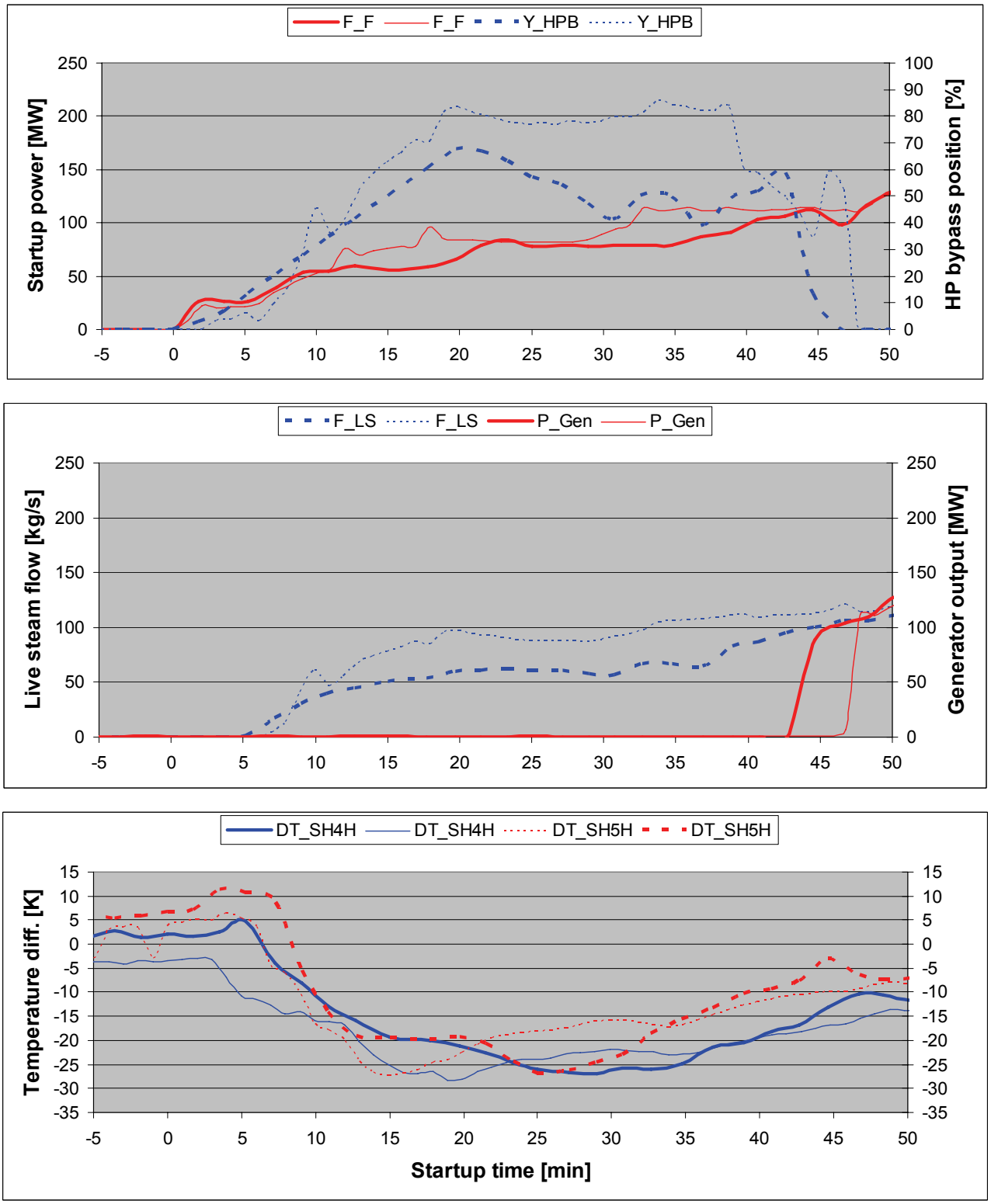

Figure 2: Comparison of two startups with BoilerMax (bold lines) and without BoilerMax (thin lines) in the Ingolstadt oil-fired power plant, unit 4. The upper diagram shows the fuel quantity F_F and the HP bypass position Y_HPB. The diagram in the middle shows the live steam flow F_LS and the generator output P_Gen. The diagram at the bottom shows the temperature differentials DT_SH4H and DT_SH5H occurring in HP headers of the two last superheater levels.

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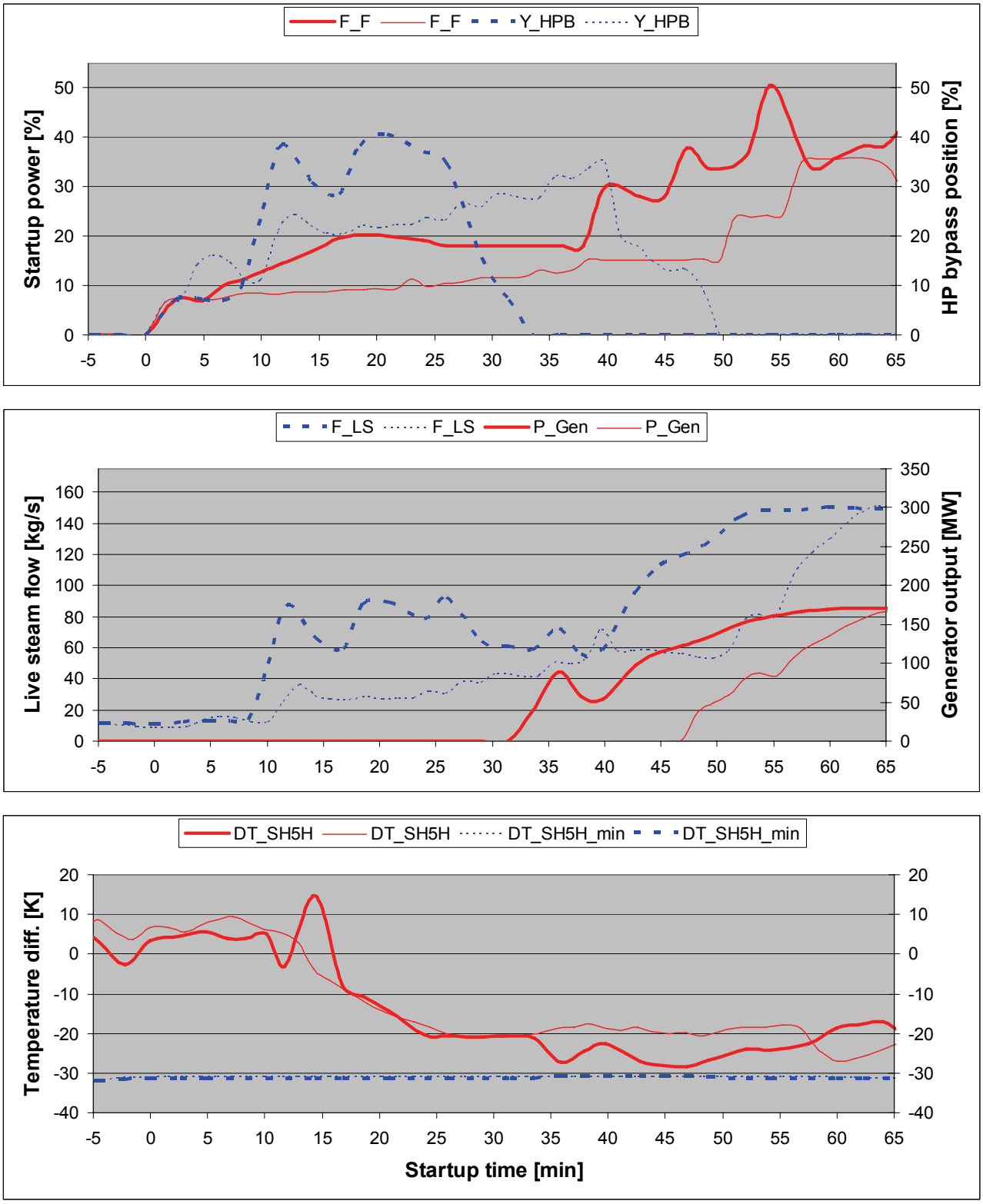

Figure 3: Comparison of two startup procedures with BoilerMax (bold lines) and without BoilerMax (thin lines) in the Zolling coal-fired power plant. The upper diagram represents the fuel quantity F_F and the HP bypass position Y_HPB. The diagram in the middle shows the live steam flow F_LS and the generator output P_Gen. The diagram at the bottom shows the temperature differentials.

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As shown in Figure 3, predictive startup optimization made it possible to better utilize the margin as early as in minute 35. This was achieved by increasing the fuel supply in the beginning at a faster rate and, at the same time, opening the HP bypass station to a greater extent. This reduced the startup time by 33%. The amount of heavy fuel oil needed for starting-up was reduced by approx. 6%. 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 approx. 11%.

Moreover, there is a high savings potential available in coal-fired power plants if the operation provides for early shifting from burning startup fuel to coal firing. In this case as well, it is important to be able to start up using a high overall quantity of fuel.

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

Operating and Monitoring

The predictive startup optimization is operated using familiar operator control features. The operator uses a customized operating screen. Fig. 5 shows the operating screen used in the Zolling PP. The left and the upper part shows 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 the ΔT limits is especially important, since 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 margins currently available so that the operator will be able to understand the setpoint settings computed by BoilerMax.

With a new 800xA process control system, the predictive data, which is 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. of disturbances.

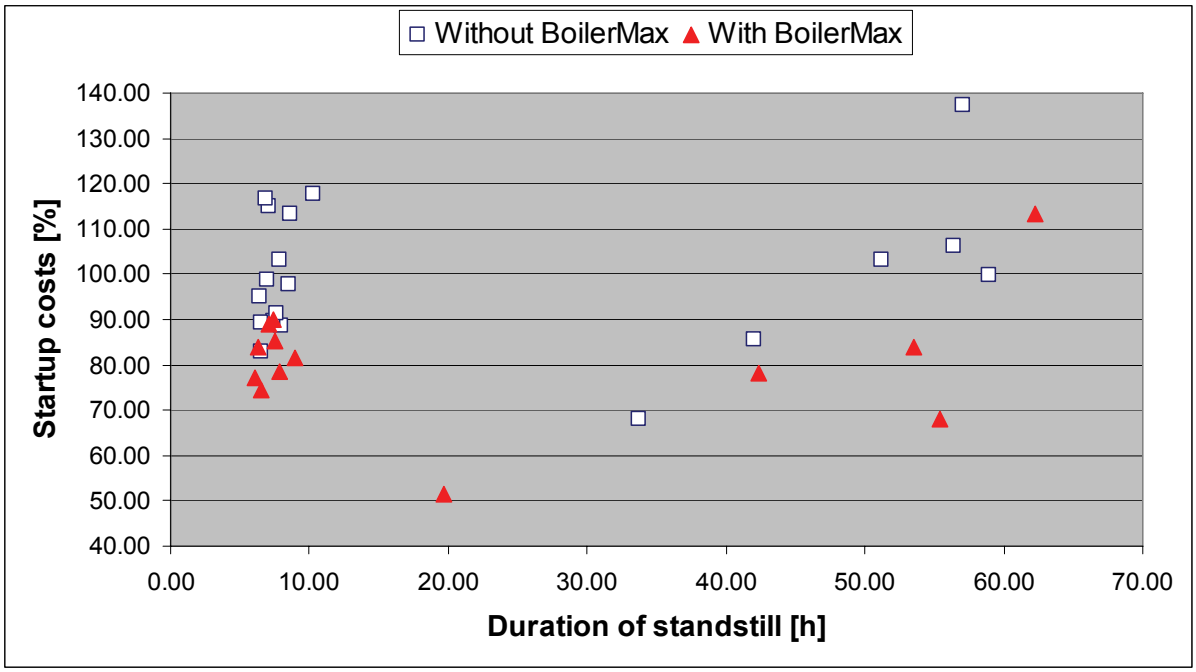

Figure 5: BoilerMax operating screen used in the Zolling Power Plant

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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.

In the Staudinger und Heyden Power Plant, the BoilerMax PC was implemented independently and be connected directly to a control cabinet. Viewing and operating are done from regular operating and monitoring stations.

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. With System 800xA, the BoilerMax PC 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 the staffs' familiarization with the BoilerMax solution and the PC can be included in the regular maintenance routines for the System 800xA. 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. The optimization results are fed back into the control system using approx. 10 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 the Staudinger power plant, unit 4, 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 are the savings potentials, as a sustained improvement of cost-efficiency will ultimately be achieved only by repeated use of the optimization function. A higher degree of automation though poses higher demands on the robustness of the startup optimization, e.g. in view of automatic detection and handling of disturbances.

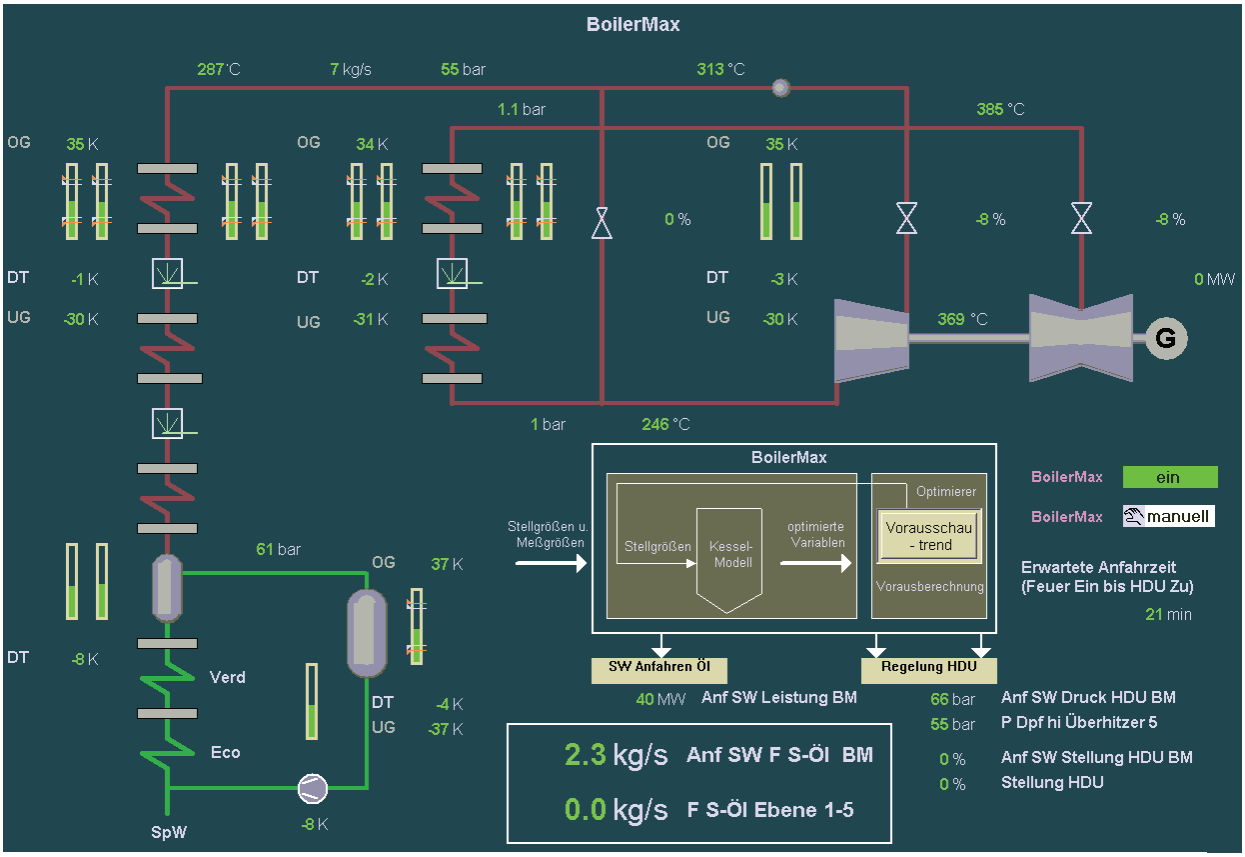

Figure 4: Startup costs as a function of the duration of the standstill in the Ingolstadt oil-fired power plant, unit 4, with and without BoilerMax.

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