ONLINE COMBUSTION OPTIMISER FOR THERMAL POWER PLANTS

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ABSTRACT: *Boiler operation is determined by dynamic behavior and transient incidents so that a true optimisation requires dynamic management and control of the manipulated variables. The paper presents a model-based boiler optimisation system based on real time adaptive, multi-variable model predictive control strategies and centered on a physical boiler model (Physical Model Predictive Control). The models predict future outputs based on the past and calculated future values of the input variables, while the physically motivated structure of the models enforces signal causality and reasonable physical solutions. The approach thus uses explicit and implicit knowledge of the process dynamic behaviour and considers all the interactions between the involved process variables.*

An important feature of the approach is to include "virtual sensors". Given sufficient data redundancy, the virtual sensor uses reliable data as an input to a model and has as its output the desired sensor information to supplement or replace the unreliable original sensor readings. We show how this additional feature leads to significantly improved overall availability. The presentation illustrates the achievable benefits of an advanced real-time boiler optimisation solution.

1.0 INTRODUCTION

Utilities and companies in the power generating market not only face the competitiveness of the global markets but have to cope with an ever increasing hunger for power while simultaneously being challenged with climate change issues and emissions regulations. Taking into account that the power sector is one of the fastest growing in India, there is a great need in improving the performance of thermal power generating units. The age of the existing fleet of power plants – many of them more than 30 years old - contributes to these problems. These improvements comprise of the increase of power generation, the reduction of related costs as well as the reduction of green house gas emissions and global warming.

Hence the search is on to find effective and efficient ways of improving plant performance, reducing emissions and costs while reliably providing power at a competitive market price. Next to building new, state-of-the-art plants to replace their obsolete counterparts there is the option of upgrading older units to meet acceptable standards, thereby keeping capital expenditure in check.

The overall performance and availability of a fossil-fired thermal power plant is predominantly affected by the steam generating unit and the combustion process. Even though conventional plant control systems ensure a safe and reliable operation, they do not rigorously optimise boiler operations or take care of special combustion problems. Not to mention that much of the information gathered by modern IT systems and advanced monitoring equipment remains untapped. Thus, many plant operators decide to unearth these "hidden reserves" by way of software driven intelligent add-on technologies supported by advanced measurement diagnostics.

An optimiser should be able to optimise these improvements in fossil-fired steam generators. The objective should be to improve boiler performance in general, considering the following performance parameters:

- Emissions reductions
- Optimise heat rate
- Increase Availability / PLF
- Reduce slagging & erosion
- Mill temperature control
- Consideration of constraints
- Cost reduction in general
- Superheater and Reheater temperature control for minimum spray water injection

2.0 MODEL-BASED CONTROL AND OPTIMSATION

Boiler operation is determined by dynamic behavior and transient incidents (load ramps, coal quality, component deterioration etc.) so that a true optimisation requires dynamic management and control of the manipulated variables. The optimiser presented is a dedicated model-based boiler optimisation system based on adaptive, multi-variable model predictive control strategies and centred on a physical boiler model (Physical Model Predictive Control). It provides real-time optimisation of the complex boiler operation and combustion (Figure 1). Using this physical understanding of the process, it differs from the numerous purely numerically driven black-box system identification approaches.

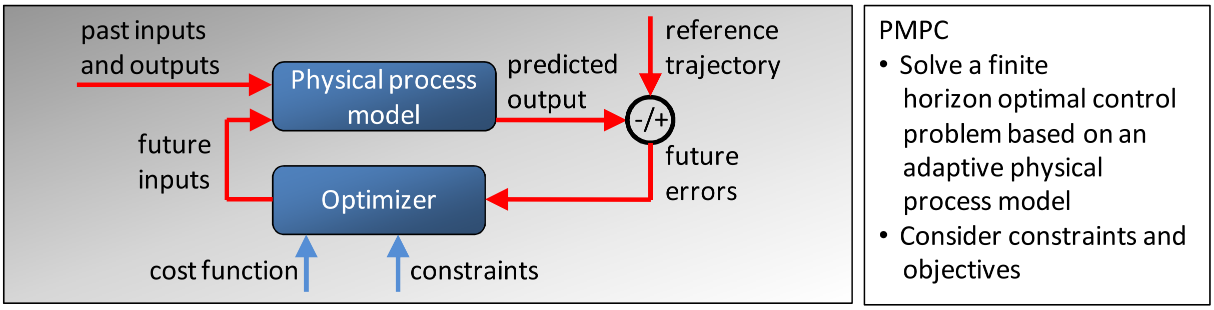

Figure 1 Principle structure of a Physical Model Predictive Controller (PMPC)

Dynamic process models represent the relationship between independent variables (model inputs) and dependent variables (model outputs). The inputs include the manipulated variables (MV), e.g. damper settings, feeder speeds as well as measured, e.g. the current load, and unmeasured, e.g. coal quality, disturbances. The models predict future outputs based on the past and calculated future values of the input variables, while the physically motivated structure of the models enforces signal causality and always leads to reasonable physical solutions. The approach thus uses explicit and implicit knowledge of the process dynamic behavior and considers all the interactions between the involved process variables. Thereby many hard and soft constraints with complex interactions must be taken care of. The optimiser rigorously reduces operational variance and shifts the operating point close to the optimum.

Optimisation is based on a multi-criteria objective formulation. A cost function incorporates and consolidates the different and often conflicting requirements/objectives by weight functions. Thereby the modular structure of the software allows for flexible and easy integration of additional objectives and constraints that may become important in the future and need to be incorporated. The system works as a set-point optimiser – an ensemble of process models incorporates and combines customer specific objectives with their individual weight functions with the various applicable constraints. The actual optimiser then adjusts the model inputs (the set-points) such that an overall optimum in terms of a weighted cost function is attained.

Periodic predictions and set-point/bias changes are calculated faster than the response time of the plant hardware including the combustion process and enable real time optimisation. The optimised set-point differentials are fed into the plant DCS system – either manually in advisory mode or automatically in closed-loop mode. A direct interference with the existing plant DCS is avoided and potentially conflicting actuator settings can definitely be ruled out.

One significant advantage of the chosen approach is its ability to dynamically handle process noise, process variability, and process drift over time, including significant process control changes, such as fuel type, or boiler draft configuration. The optimiser automatically adapts to changing plant conditions by continuous online re-tuning, as required by operating conditions and discerned by the model confidence intervals. This on-line adaptivity ensures that the control system not only does the right thing, but also that the models accurately reflect the generating unit's actual operating conditions, deal with instrumentation drift and recalibration, disturbance rejection, model mismatch, equipment performance degradation and maintenance. This approach provides continual, automated improvements to boiler control.

3.0 ENHANCING THE DATA BASE

In some cases, the performance of the optimiser may be significantly enhanced by extending or improving the available measurement data base in the plant by advanced diagnostics. A good example is the accurate measurement of the two-dimensional temperature distribution at the furnace exit by an array of optical pyrometers (refer also chapter 4.0). This straightforward information can be used to centre the flame ball. Moreover it helps to identify the optimal trade-off between the flame ball position and the amount of spray water injected for balancing the main-steam temperature at the exit of the superheater and reheater. Spray water injection has a negative impact on the heat rate and as such it should be minimized. But to what extent? Certainly not to the extent of completely displacing the flame position to compensate for the temperature differences, as this may cause other adverse effects.

In other cases the installed measurement technology may prove unreliable. With sufficient data redundancy in place, a soft or virtual sensor may be constructed which uses reliable data as an input to a model and has as its output the desired sensor information to supplement or replace the unreliable original sensor readings. Figure 2 shows the example of a flue gas temperature sensor that is replaced by a smart sensor model with sufficient accuracy and much higher reliability. This approach is again motivated by the desire to maintain physical causality and plausibility.

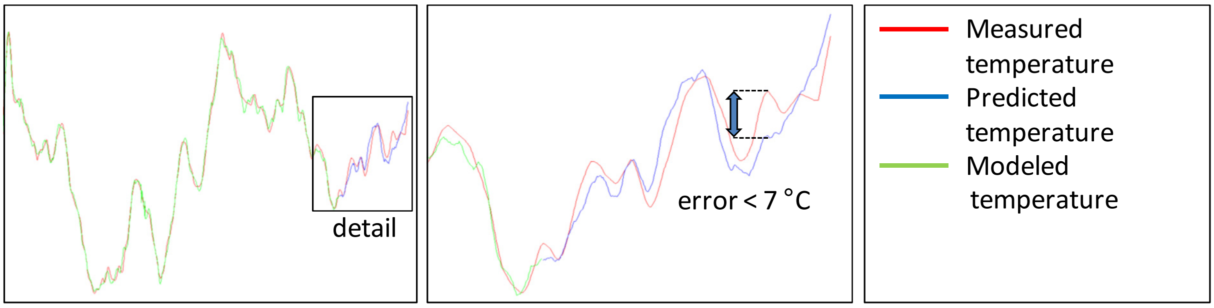

Figure 2: Temperature prediction over 4h using a soft sensor based on redundant process data

4.0 ONLINE TWO-DIMENSIONAL TEMPERATURE MAPPING (FGET)

The technology to monitor and analyse temperature distribution in the boiler is based on optical flame sensors, measuring temperatures anywhere between 600 °C and 1,400°C (other temperature ranges are also possible). The sensors, specially developed for coal-fired plants, measure at two wavelengths and not only determine the black body temperature, the quotient temperature but also the true flame temperature via a special algorithm. Apart from this, the simultaneously measured optical thickness gives valuable feedback on the cleanliness inside the boiler. By continuous and automatic monitoring and analysing of the flame temperature, optical thickness and temperature distribution the plant operators can optimise the boiler operation. Additionally the optical pyrometer offers the possibility to monitor the flame with a video camera. This option allows continuous monitoring of the free access to the furnace as well as the sooting optics. In case of failure, the system informs the operator about the necessity to clean the optics.

More important the system allows the continuous determination of the two-dimensional temperature distribution and the fluctuations at one level inside the furnace by use of multiple flame sensors. Through data processing, the current and historical temperature distribution of the boiler can be visualised at any time allowing a quick assessment of situations. The software controls all optical sensors and informs the control room continuously about the actual temperature, optical thickness and the operating conditions.

In combination with the optimiser it makes the best of the available information within a control loop. The optimiser helps to center flame ball position, reduces the end of furnace temperature or helps to impose a low fouling combustion strategy.

5.0 PLANT IMPLEMENTATION

The optimiser connects to any underlying automation system via a standard protocol. If required proprietary DCS communication protocols can also be addressed. In a typical configuration as it is depicted in Figure 3, the communication is fed through a data base server, which in turn reads data and sends control commands to the underlying automation system or DCS. Hardware and software redundancy is established.

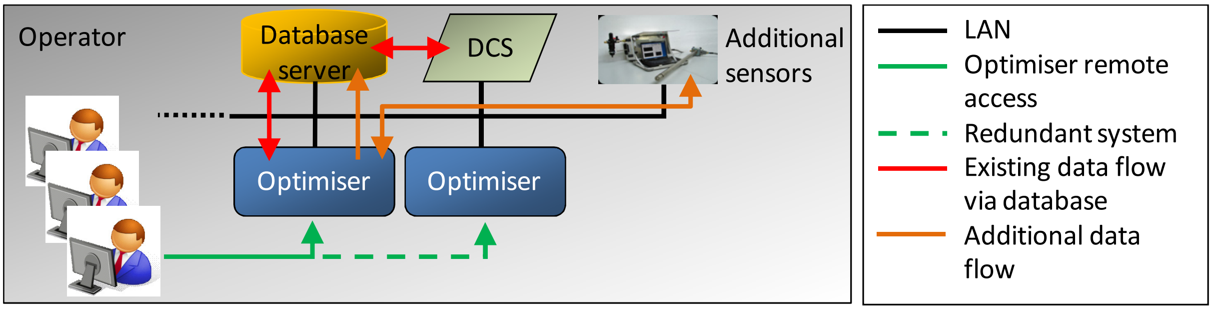

Figure 3: Integration of the add-on optimiser into the plant automation and communication structure

A web based client-server structure allows for remote (observatory) desktop access through plant engineers from within the plant´s LAN and service and maintenance tasks can be done from external remote access.

The configuration is easy and straightforward and is done via an intuitive graphical user interface, Figure 4. Optimisation is multi-criterial and based on a cost function that incorporates and consolidates the different and often conflicting objectives by weight functions. Parameter settings are adjusted, hard and soft constraints are defined and alarm thresholds are set. Various configurations can be predefined and stored for later use. During operation engineering and reporting tools assist the user in data visualization, performance monitoring, and engineering analysis.

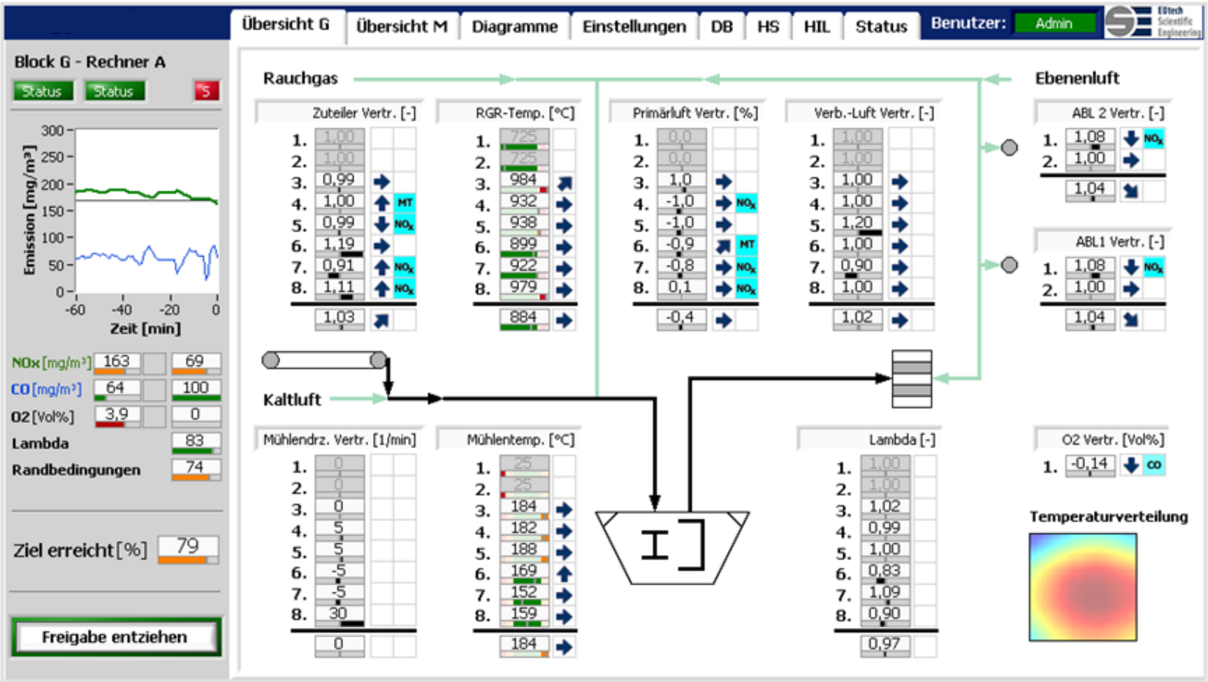

Figure 4: Intuitive user interface – controls at fingertips

6.0 ACHIEVED BENEFITS

Combustion optimisation adjusts the fuel and air biases within the furnace to improve the combustion process, thereby controlling emissions. The NOx-CO trade-off is looked after by adjusting the air dampers, mainly along the “vertical” boiler axis, adjusting primary, secondary and, if available, over-fire air (OFA) in conjunction with the excess oxygen control. This trade-off is a very essential aspect not only in terms of heat rate but also in terms of boiler slagging. Fuel-air imbalances at the burner level lead to incomplete combustion in the lower furnace and coal particles will hit the convective boiler sections at too high temperatures, which sometimes may even exceed the ash fusion temperature. This is a situation that must be avoided. Low-NOx strategies, if not carefully implemented and controlled tend to mask unfavorable combustion.

The excess oxygen level plays an important role for achieving minimum heat rates. Biasing O2 levels downward by only 0.2% on a long term basis under otherwise constant conditions leads to significant heat rate improvements above one percent.

Both emission and excess oxygen control strategies are depicted in Figure 5. The NOx- and CO-emissions are controlled and held just below their limits, while the overall excess oxygen is simultaneously being reduced. Further investigations show that the reason is the improved fuel air mixing which leads to more vigorous and complete combustion in the reaction zone at burner level. Figure 6 shows how the optimiser changes the combustion regime by shifting more air to the burner level and reducing OFA – entering areas otherwise untouched. The integration of air flow ‘measurement’ based on soft sensors additionally improves the situation. Not only in terms of further reduction of access oxygen but also in terms of more robust and stable boiler operation.

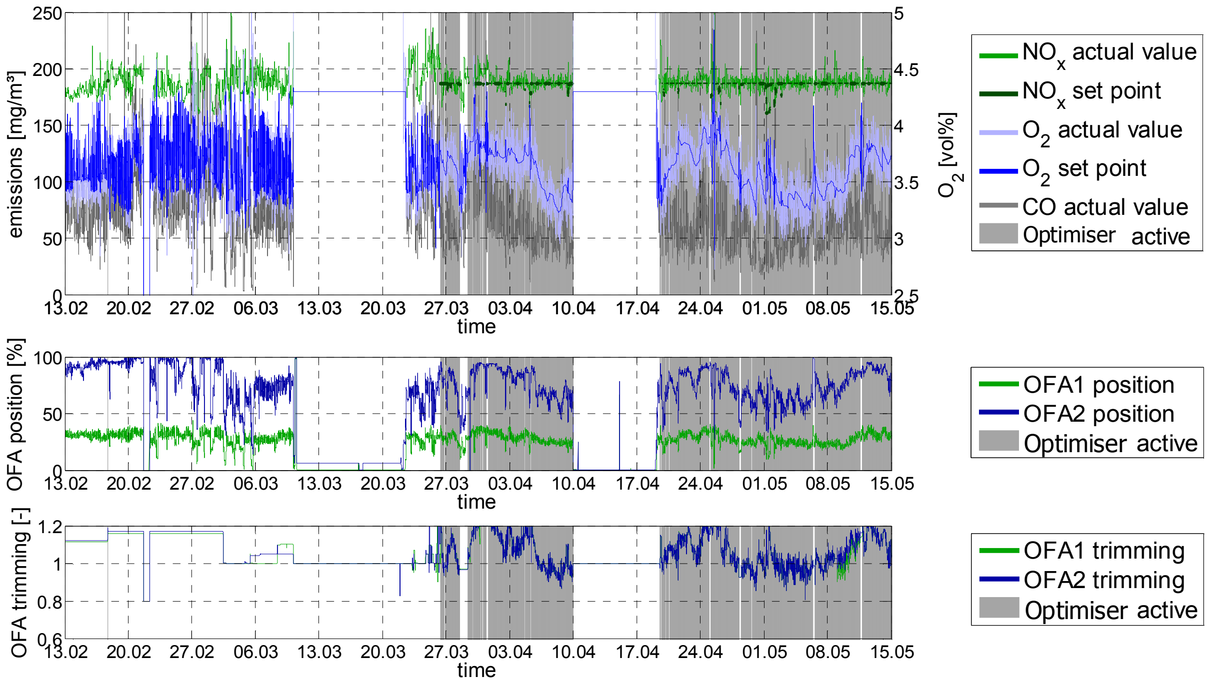

Figure 5: Emission control and excess O2 reduction

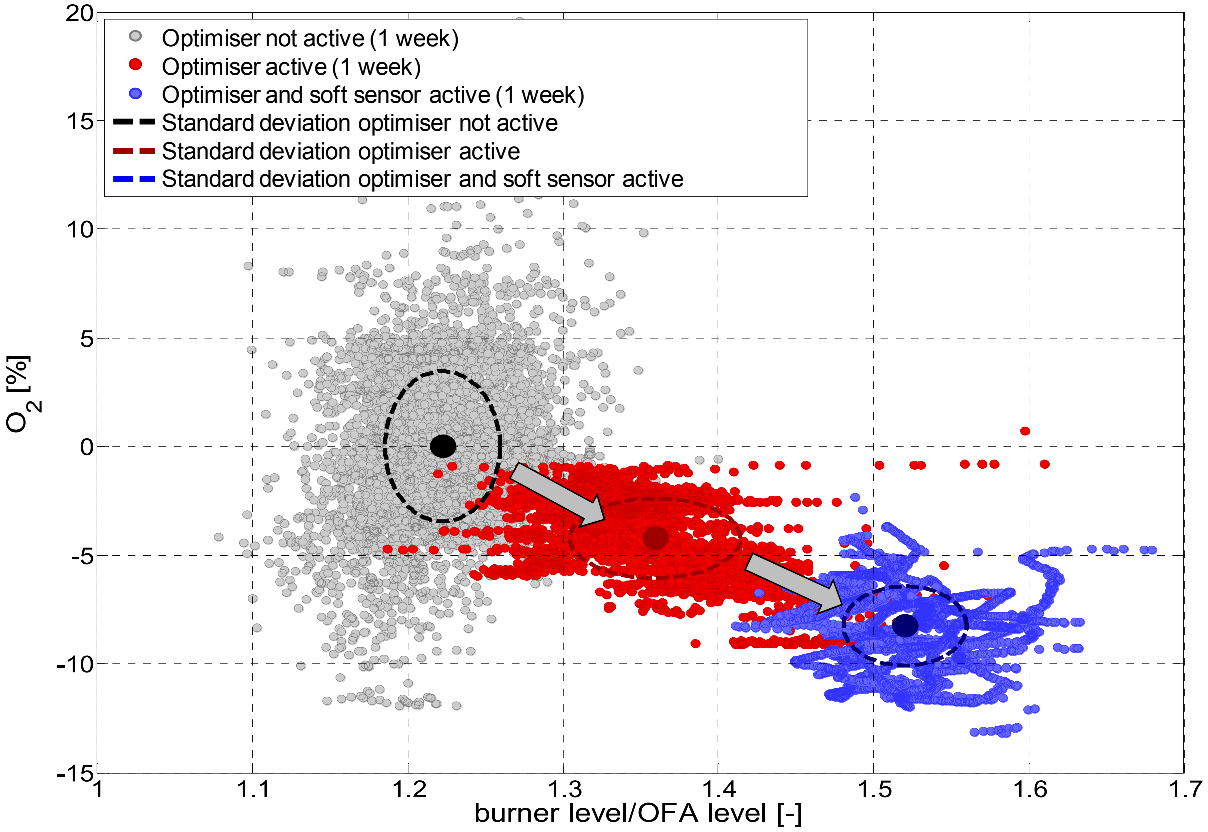

Figure 6: Changing the regime of combustion with optimisation

In the case of lignite fired boilers the “horizontal” balancing of the air-fuel ratio at the burner level further contributes, as shown in

Figure **7** (top), to this improvement. The optimiser narrows the air-fuel band at which the different burners operate.

This is not quite a simple task since the mill temperatures must be kept under control. The mill temperature is governed by the primary air, the coal load (feeder speed), the mill speed and the classifier settings. Commonly, the primary air adjustment is used to control the mill temperature, since the coal feeders have to maintain a through-put according to the unit load demand while the classifier settings have to ensure a coal size spectrum that is optimal for combustion. The optimiser uses an ensemble of physical models for each mill that are continuously adapted taking account of degradation, wear & tear and coal quality changes. The lower part of

Figure **7** shows that the optimiser can handle this constraint with ease.

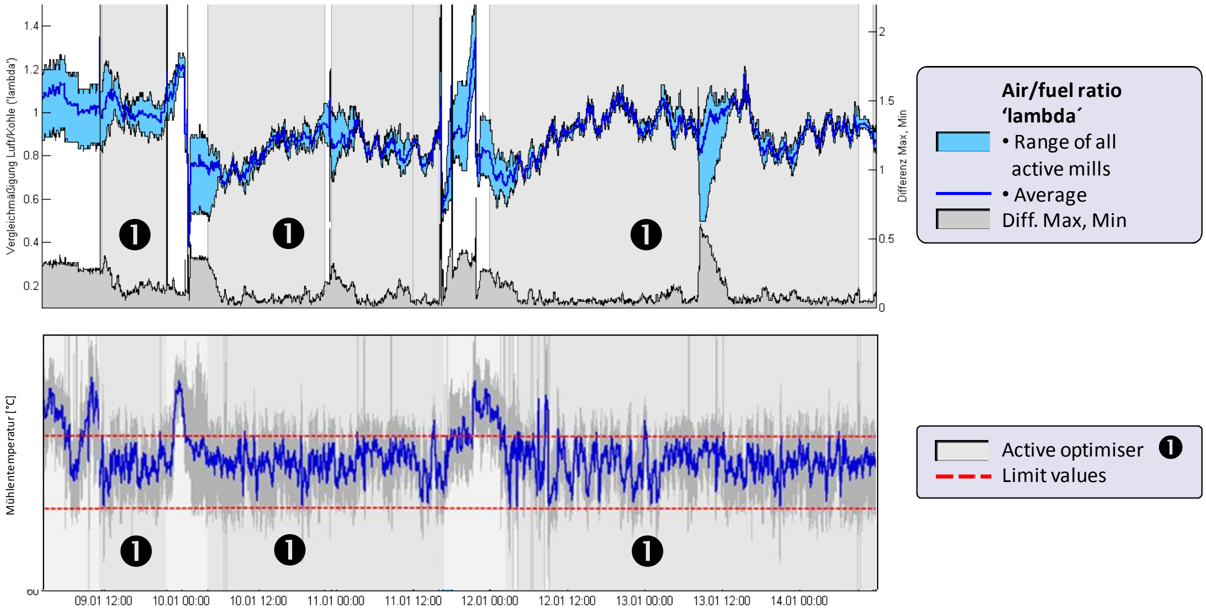

Figure 7: Air fuel ratio (top) and mill temperatures (below) with and without optimisation

Reasons for limited/reduced availability are manifold. The opportunity cost (lost profit) of reduced availability are enormous: Assuming a 10% profit on the sales price the opportunity costs for the same 500 MWel block amounts to 36,000 EUR per day – this does not include the cost of repair.

The opportunity cost (lost profit) associated with reduced availability are enormous and need not be elaborated upon. Fortunately, plant availability is affected very positively in that the optimiser streamlines the fuel air distribution and balances the fuel lines, takes care of intricately interdependent constraints, and avoids local temperature excursions, excessive slagging, material stresses or other operational irregularities. Additionally incorporated fault diagnostics help to detect and identify anomalies corresponding to measurement problems, signal quality or changing process behavior. Often, problems can be identified early on and damages or even forced outages can be reduced.

7.0 REFERENCES

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