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Fully Automatic, Self-Learning Process Optimization to Increase the Efficiency of Large-Scale Power Plants

Software-Based Correlation of Process Control System Data with Optical and Acoustic Information

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Abstract

Economic requirements have imposed new challenges on the performance of hard coal fired steam generators in large-scale power plants. Major quality fluctuations, especially of imported coal, and design- and coal-related irregularities of the pulverized coal distribution have led to a sub-optimal distribution of combustion air with classic control approaches. A direct negative impact on plant efficiency has been the result.

Now, by using a control system package which comprises intelligent software, optical sensors for the flame analysis and acoustic sensors for determining grinding fineness, a method has become available for optimizing the fuel/air ratio per individual burner and across burner levels. Plant control system data on the combustion process are continuously read out "on line" via an interface, and are then correlated with optical combustion parameters and acoustic mill information. Setpoint adjustments calculated from these findings are written to the plant control system from where they are passed on directly to the actuators. These improved actuating commands yield a continuous optimization of the combustion process.

As a result of this improved combustion management, the plant will benefit from a more uniform temperature distribution per burner level, an optimized temperature profile for each given load level, a higher efficiency, improved performance dynamics, and diverse further improvements in its combustion chamber parameters. This, in turn, yields benefits such as a 1% reduction in coal consumption, a corresponding drop in CO_2 output, and a more-than-proportional reduction in slagging, NOx and CO.

Efficiency improvement challenges

The challenges regarding efficiency improvements of the coal-fired steam generator in large-scale power plants often reside in the following objectives:

1. Coal is a non-uniform natural product, and an increasingly broad coal band is employed to optimize costs.
    - As a result, coal bands will often exhibit differences in calorific value, ash content, volatiles, milling properties, etc.
    - Key coal data are at times inaccurate, or the available information only rarely holds true for the entire coal shipment.

    - The degree of grinding fineness varies with coal grindability and with the condition of the mill.
2. A further challenge lies in the non-uniform distribution of the pulverized coal flow, whether at a given burner or across levels, mainly as a result of
    - irregular routing of pipework, giving rise to a non-uniform supply to the burner(s)
    - absence of an automatic response to the coal flow measuring system, which, indeed, is absent itself in many cases or fails to meet accuracy expectations where it exists;
    - absence of a continuous and automatic response to equipment drift, especially of the mill, screening systems and burners.
3. As a result of the foregoing, a sub-optimal distribution of combustion air on the individual burner and across steam generator levels will be experienced and gives rise to
    - increased fuel consumption;
    - higher emissions;
    - unnecessarily high loads on individual equipment units.

Other challenges, which may vary between boilers but whose solution would likewise yield improved availability and/or better efficiency rates, can be indentified in the following phenomena:

1. burner backfiring due to slagging
2. intense overall susceptibility to slagging
3. CO pluming due to slagging and/or sub-optimal fuel/air mixtures
4. temperature problems (thermal stresses on steels and refractory lining)
5. high levels of unburnt carbon in the ash (UciA)
6. boiler inertia

However, the greatest challenge of all in devising an optimizing combustion control system lies in the concurrent pursuit of competing optimization targets. This complex situation is further compounded by fluctuations in calorific values, coal qualities and degrees of milling fineness, plus the associated differences in ignition and burnout rates. At the same time, the aim is to maximize the equipment's energy efficiency and to maintain process conditions as constant as possible, thereby running the plant as smoothly and hence, as sustainably as possible. Moreover, emission levels and unburnt residue should be minimized. All of the above can be addressed by creating an optimum fuel/air balance, which is the hallmark of an optimized combustion process.

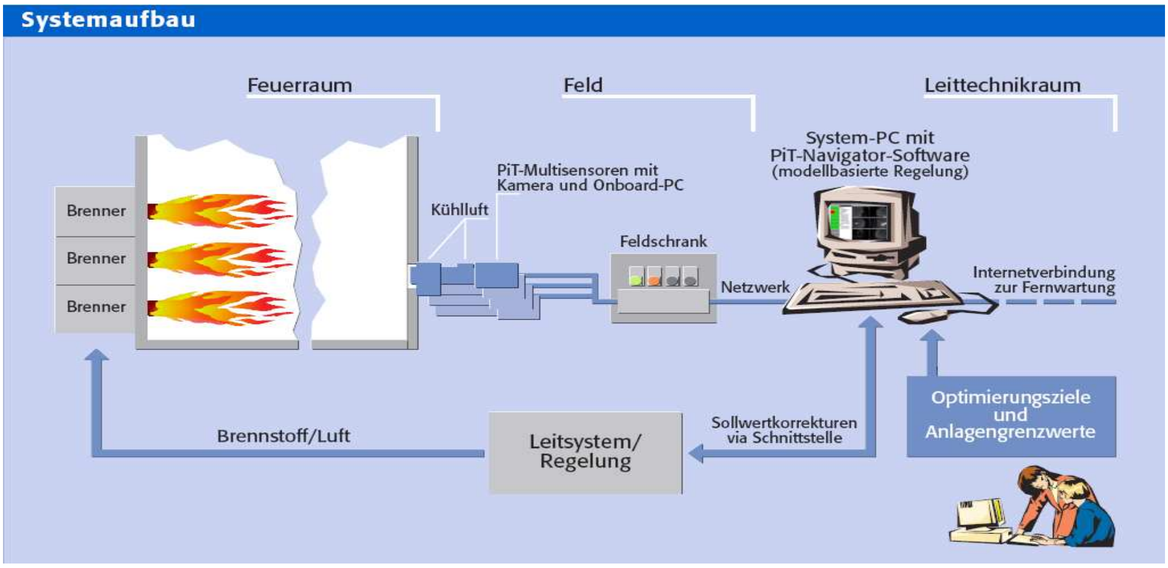
Overcoming these challenges calls for additional information, both directly from the mill system and from the core of the process, i.e., the fire itself – the type of information which the mill master obtains by putting his hammer on the mill and placing his ear against the end of the handle, or which the burner expert gains from looking at the flame of an individual burner or of the overall flame body.

This requirement has given rise to two visions:
A) If mill and flame data could be made available in digital form so as to become correlatable with other data obtained from the process control system, it should be possible to generate continuous automatic control interventions in order obtain an optimizing control capability.
B) This optimizing control capability should require no ongoing manual re-

programming and re-parametrizing, but should, through a self-learning process, keep on improving itself on the basis of the process states experienced while adapting to new process states on its own.

The solution

The structure and characteristics of flames and flue gases are analyzed with the aid



of optical sensors looking at the burner and the flame body. Mill vibrations are monitored via piezo-ceramic sensors on the mills, screening units and pulverized coal lines.

[Legends]

Feuerraum	Combustion chamber
Feld	Field
Leittechnikraum	Control room
Brenner	Burner
Kühlluft	Cooling air
PiT-Multisensoren mit …	PiT multisensors with camera and on-board PC
System-PC mit ….	System PC with PiT navigator software (model-based control)
Feldschrank	Field panel
Internetverbindung …	Internet connection for remote maintenance
Brennstoff / Luft	Fuel / air
Leitsystem / Regelung	Plant management / control system
Sollwertkorrekturen	Setpoint corrections via the interface
Optimierungsziele und .,,	Optimization targets and plant limit values

These data are processed by a non-linear predictive control system based on self-learning neural networks. In conjunction with conventional process parameters, it permits a real-time prediction of process responses (e.g., temperature, steam flow, O_2, NO_x, CO) to simulated control interventions made in the process.
The analysis of all possible predictions yields an optimum plan for the correction of all manipulated variables, which are then fed back into the process control system in real time. It thus becomes possible to achieve weighted optimization targets which may also consist of a weighted compilation of different individual targets. Figuratively speaking, the process control system is given ears, eyes and a brain by this approach.

Flame structure analysis

To optimize the combustion process, it is essential to understand the flame and the flue gas as essential information sources, and to make use of them as such.

The control of the combustion process is defined mainly via the fuel/air ratio and an optimum air distribution in the boiler. A high excess of air will reduce the flue gas heat loss, which is reflected in an increased energy consumption of the associated fans. A scarcity of air, on the other hand, will drive up flue gas NO_x concentrations and the level of unburnt fuel in the ash. Moreover, the flue gas will be more corrosive overall, it will attack the tubes in the steam generators (finned walls) more aggressively and thereby reduce their service life. Establishing the right air-to-fuel balance is therefore critical when it comes to minimizing operating and maintenance costs.

The availability of current measurement readings is a key prerequisite for accurate control. Accordingly, readings must be obtained straight from the process. The video-based camera systems frequently employed provide the plant operator with data on flame behaviour, but the correct interpretation of this complex information remains contingent on his individual skills. Whether or not the right conclusions are drawn will depend on his experience level and monitoring intensity, which can certainly not be kept high for 24 hours/day, 7 days a week.

To obtain accurate combustion process data beyond the temperature measurement, an intelligent flame and flue gas analyzing system was developed. This system extracts information directly from the flame and the flue gas and performs a substantially more accurate combustion analysis. The data obtained is available in digital form and can thus be correlated with measurement readings taken on the plant itself.

Aside from a location and time-related temperature analysis, the flame intensity and frequency as well as the volume and shape of the flame are permanently analyzed. This is achieved using cameras with an on-board PC, which monitor the process through endoscopes. The integrated digital image processing system supplies key process parameters such as the flame position and volume, turbulence, dwell time and flow behaviour with a high dynamic response rate and high degree of spatial and time resolution. Since these parameters correlate with emissions (CO, CO_2, NO_x), a unique information source becomes digitally available in near real time.

Depending on the boiler geometry, between 2 and 12 optical sensors are used. The sensor lance comprises an endoscope and is air-cooled. A special purge air head is used to prevent foreign matter from obstructing the view of the flame. A high-speed camera is fitted in the external housing and allows the flame to be monitored with a high degree of resolution in space (1024x1024 pixels) and time (2300 – 4000 Hz).

The sensor mounting locations depend not merely on the individual burner geometry and burner arrangement, but also on individual operator objectives. Mere centering of a flame cyclone in a corner-fired boiler can be achieved via two sensors on the upper air level. On the other hand, where operator objectives require an optimization of the flame on the individual burners, it is necessary to have multiple sensors per burner level. Thanks to digital image processing technology, it is also possible to monitor several burner flames with one sensor and to separate the individual flames perfectly in the analysis.

The ideal monitoring point lies to the side of the burner so that the burner mouth and flame root, as well as the main combustion area, can be analyzed. However, an adequate amount of information can be achieved even with a sub-optimal arrangement, i.e., looking vertically onto the burner.

The sensors quickly supply a large quantity of repeatable, significant signals directly from the combustion chamber for digital image processing. These signals are characterized by an adequate signal strength and a high degree of correlation with combustion efficiency parameters. The following particular characteristics deserve to be noted:

- **High dynamic response range** due to the use of exposure time series for all colour constituents (red, green and blue). Permanent variation of the camera settings make it possible to obtain very dark and very bright images, with high contrast, at the same time.
- **RGB thermography:** Pixel-by-pixel processing of 10 to 4000 images per second from different wavelength ranges (temperature calculation by a method similar to ratio pyrometry). "Each pixel point is its own independent pyrometer."
- **Electronic dust filter:** Reduction of dust in the individual image through a patented electronic dust filter, i.e., images are built from highly useful components of a large number of individual images.
- **Sensor contamination signal**: For status-based maintenance purposes, the degree of sensor (lens) contamination is continuously indicated.
- **Endoscope with powerful light beam:** Powitec's special endoscope technology minimizes the loss of visual information.

The data obtained automatically and continuously from the complete flame analysis are employed to identify correlations with further data from the process control system in order to optimize the process.

The result is a set of information and stochastic characteristics describing space- and time-related changes in
- the local fuel/air mixture
- the flame intensity and temperature
- flow and flame fluctuation

Vibration analysis

The vibration analysis is based on the observation that mill characteristics (i.e., power train and grinding tool behaviour) and the consistency of the coal mix give rise to different vibration patterns, and that the load, coal properties and mill wear are reflected in acoustic properties.

Whereas the mill produces rather continuous, low frequency sounds, the screening system tends to yield periodic ones within a narrow range. The coal, on the other hand, emits a quite stochastic, broad band of high-frequency, discontinuous spectra. By analysing the level and spectrum, it is possible to derive scalar features.

The data collection requires an appropriate positioning of the sensor, determined after a one-day on-site measurement. The military-approved, industrial grade piezo-sensors are magnetically attached at points <120°C. The data obtained there are centrally fed to a separate high-performance server for the acoustic analysis. Here, the data evaluation is performed by analysis of spectral focus points, statistical moments, and correlation analysis (optimization of the transformation content). In other words, the wealth of information obtained is reduced to data exhibiting the greatest information content and the largest statistical independence between variables.

Through analysis of the frequency bands, spectral foci, statistical moments of the vibration spectrum, and calculation of a set of envelope curves (parametrized envelope filter) including their statistical moments, a correlation and entropy analysis can be carried out.

The result is a reduced set of period and stochastic characteristics yielding an optimum information content with regard to

- grinding fineness
- mill conditions
- changes in pulverized coal flow per coal line

Process data

Reproducible process data are a necessary precondition for process optimization. The optimization software is linked to the existing process control system via a bidirectional interface (e.g., Modbus, Profibus, OPC). All (!) existing setpoint and actual data of the combustion process, from the feeder through to emission data, are continuously read.

- feeder system r.p.m.
- mill flow, mill moment
- mill pressure differences
- mill air valves (hot/cold)
- secondary fuels, if any
- screening system settings (e.g., rotational speed)
- laboratory parameters: calorific value, ash, water, volatiles
- laboratory (or on-line) values of unburnt carbon in the ash (or, residual C)
- live steam flow rate
- electrical load and frequency
- steam flow rate
- steam temperatures and pressure
- thermal output setpoint
- flue-gas temperatures
- induced draft
- carrier air (primary air)
- secondary air
- staging air (tertiary air)
- overfire air (individual and summarized)
- secondary air flows (valve settings) and temperatures
- lance blower Start/End
- O_2 (e.g., upstream/downstream of the Economiser)
- sour gas NO_x

- sour gas SO_2
- sour gas CO

Data processing

A certain engineering effort is required to filter down the very broad range of existing measurement data and to define appropriate pre-processing parameters which carry the information needed from a control technology viewpoint. To this end, Powitec has developed solutions which provide a largely automatic configuration in terms of channel selection and parametrizing. These techniques are not limited to the classic control system measurements but are capable of automatically extracting action-relevant features from the highly dimensional and hence, much more voluminous data flow of the images, cameras or vibration sensors.

From the crude data, features are initially extracted using a basic filter system (feature extractor). Between these features and the target variables of interest, a measure of information is then calculated which indicates how much insight these extracted features provide with regard to the target variable. Using a special optimization process, the feature extractor is then adjusted so as to provide features of maximum information content regarding this target. By means of this method, the necessary control information to be made available to the actual control system (as a working basis, so to speak) is taken from the available data flow in a fully automatic manner.

Similar to this automatic feature extraction, a self-organizing concept is also used in selecting the manipulated variables to be relied upon. Typically, a whole series of manipulated variables is available for control intervention on the steam generator, but it is usually unclear which combination of these variables is capable of achieving the defined optimization matrix. A suitable combination of manipulated variables is determined via an automatic analysis of each manipulated variable's effect strength and side effects on other target variables.

Analysis and prediction

The information gathered on the pulverized coal, flame and flue gas are correlated with the data from the process control system and provide input for the PiT Navigator optimization software based on a self-learning, adaptive neural network. The software cooperates with all common process monitoring systems via an interface (e.g., Modbus, ProfibusDP, RK 512, OPC). From these data, control parameters and their optimum modification are automatically determined. This takes place on the basis of process models capable of learning interdependencies between the flame characteristic and other process parameters.

These process models enable the PiT Navigator to predict process responses (temperature, emissions) for the next 2 – 3 process steps, thus providing a view of the near future.

Varying process conditions, wear-related equipment drift or fluctuating fuel properties can thus be detected and optimized automatically.

Neural networks have been criticized for their limited ability to provide sustainably effective process modelling in the face of varying fuel characteristics. However, the software described above (in conjunction with optical and acoustic sensors) is capable of analysing the process and responding to it with self-learning adaptivity. This gives rise to outstanding process models. It is on the strength of these models that Powitec's states its claim of possessing a head start of 3 to 4 years over its competitors.

Optimization

The PiT Navigator takes into account the plant operator's specific optimization targets. The latter are defined by the management in the form of a (weighted) hierarchy. By continuously taking into account all sensor output (process data) and controlling all actuators (mill system, combustion chamber), the system can realize hitherto unknown optimization potentials. Some optimizing systems are based on fuzzy logics, requiring a custom definition of associated rules for the specific plant. Only expert knowledge is thus written into the system; no automatic permanent optimization will take place. Due to continuous plant drift and plant component modifications, it will often be necessary to adapt or even re-write these rules on a continuous basis. The neural networks described herein will likewise embody the plant operator's know-how, but the software learns on its own and continues to optimize the process even after a plant or process change, or during major fluctuations in calorific value, without any manual intervention. In addition, no permanent updating to allow for plant drift is necessary, so that the user becomes less dependent on the individual software and process experts. On the other hand, the plant operator is by no means made redundant, since the system is only an optimizing tool and its control action is restricted to the firing performance diagram. Plant run-up and shutdown processes are still carried out manually by the operator.

Operation

The PiT Navigator consists of several controller components.
Each of these components receives signals from the process interface and from the optical sensors. Moreover, described predictions are used.

Targets are defined for each controller component, and each controller component pursues the targets defined for it. The individual component's parameters are determined via the preset values on the one hand and, on the other, by parameters optimized via the self-learning process.

The speed and intensity of controller interventions is agreed upon between Powitec and the plant operator.

As a result, the success of the PiT Navigator depends on

- defined targets
- the plant's technical capabilities, and
- the permitted magnitude and speed of controller interventions

The PiT Navigator pursues different **strategies:**

- **Early detection**
  Detection of changes in milling fineness, pulverized coal distribution and flame pattern, facilitating a rapid response.
- **"Self-calibration"**

Conventional fuzzy logic controllers need to be re-parametrized regularly. With the PiT Navigator this is not necessary, since as a self-learning multi-variable controller, it continuously and automatically generates up-to-date process models and controls the furnace accordingly. Thanks to this "self-calibration", all changes in the equipment (wear, slagging, dirt accumulation, etc.) and fuel are detected and taken into account.

- **Independence of manual modelling processes**
  The neural network is trained and learns process models on its own, contrary to manually prepared mathematical models which depend on the respective expert knowledge.
- **Adaptivity**
  A continuous automatic optimization takes place, experience is stored in memory and re-used when necessary. No process state learnt by the system is forgotten, and the automatic adaptation to changing process states never ceases.
- **Broader view**
  Since the scope of the analysis extends to the mill, pulverized coal lines, the flame and the flue gas, new information is gained and correlated with relevant current and historical process data. The result is a broader process view, in terms of both locations and time.
- **Utilization of all plant technology options**
  The software continuously controls all actors with an intensity and degree of resolution no human operator could achieve.
- **Homogenization**
  The system provides a more homogeneous temperature distribution, not just at the burner level but across levels. Moreover, a homogenisation across staff shifts is obtained through full automatization.

One key benefit of this self-organizing, self-optimizing control concept is its inherent adaptivity. The latter is achieved by cyclic re-training of the underlying process model using current data material. This is possible because the process is automatic and hence, involves no manpower input whatsoever. In order to ensure that the process model, thus newly trained on current data, can actually be used for controlling the process, a number of criteria must be met. Thus, it is examined, for instance, whether the updated model using the current test data actually gives a better description of the real process than its predecessor. Moreover, the data set used for training is statistically evaluated for whether it actually depicts typical process behaviour and not, say, a plant shutdown situation. Thanks to such cyclic re-training, testing and (where applicable) updating of the neural process model, time-related variations in the combustion process due to fuel changes, slagging situations, etc., can be automatically addressed.

Effect

The effect produced in the combustion chamber essentially covers five areas:

1. The temperature distribution per burner level becomes more uniform. Thanks to the additional analysis of the local and time-based temperature distribution, a plant running the optimizing system will operate in a demonstrably more uniform manner than one not equipped with the system.
2. The average temperature in the combustion chamber will be maximized, within given limits, since the adiabatic isobaric combustion chamber temperature rises

with the optimization of the fuel/air ratio and the associated redistribution of air flows and reduction in the lambda value.

3. Depending on the coal quality, mill condition and power demand, the temperature distribution is optimized across the levels (based on the states learnt), so that an optimized heat transfer is obtained for the currently demanded load profile.
4. The efficiency η of the heat exchanger (η steam generator = Σ steam energy / Σ fuel energy, or η steam generator = 1 – Σ boiler loss / (Σ steam energy - Σ losses) is improved by the average reduction in fuel/air consumption (reduced lambda, or reduced O_2) and by the reduction in unburnt matter in the residual ash (or reduced residual C value). An improvement in the steam generator efficiency by 0.3% corresponds to an 0.1% increase in the efficiency of the power plant – a small figure, but one with important implications (see "Results") for the coal consumption.
5. An improved performance dynamics (speed of unit adaptation to changes in load demand) yields substantial benefits in the case of rapid load demand variations and is achieved by reducing the boiler inertia through an optimizing control of the flame hotspot and an optimizing control of the mill field. The result is a one-third drop in the boiler time constant.
6. Other beneficial effects exercised on the steam generator by the active flame control system, although difficult to express in monetary terms, include the following:
   - reduction of unburnt carbon in the ash (UciA), even with difficult boiler geometries and/or ash-containing coal
   - reduced susceptibility to slagging
   - verification of burn-out per burner
   - elimination of burner backfiring
   - improved boiler wall atmosphere (reduced CO pluming)
   - elimination of temperature imbalances
   - reduced NO_x emissions

Results

The optimization solution described above is currently employed in day-to-day service on 6 hard coal-fired steam generators and 18 waste-to-energy steam generators. The results achieved on hard coal-fired steam generators can be summarized as follows:

Komipo

At **Komipo** Seocheon TPP, a roof-fired plant with 20 burners per boiler, the installation has been active on both boilers since 2005. A total of 2 x 215 MWel is generated here. One particularity in this application lies in the use of a lower-quality local coal having an elevated (50%) ash content. The optimization solution has been able to reduce unburnt carbons in the ash by 0.8% abs. on the No.1 and by 1.2% on the No. 2 boiler.

Evonik

At the **Evonik** power station in Fenne, the optimization system has been in use since 2005 on one boiler with staggered opposed firing (8 burners on 2 sides on each of 2 levels) and 4 mills.

The software controls the secondary air distribution per burner as well as the sewage

sludge quantity. Under a performance-based contract between Powitec and the utility company, Saarenergie (now Evonik), the savings obtained with the installation are split between the two companies over a 7-year period.
The results for 2006, 2007 (VGB PowerTech, Dec. 2007, Dirk Kiehn et. al. „Performance Contracting for a Firing Performance Optimizing System based on Neural Networks in a Coal-Fired Power Station) and 2008 show the following:

- steam generator efficiency: + 0.4% = -324 t coal/a = - 2768 t CO_2 /a
- O_2 airflow: -24% (down from 4.2 to 3.2 %, or λ 1.25 to 1.18)
- own consumption: - 2000 MWh/a
- UciA: - 0.15% (down from 4 to 3.85%)
- improved boiler wall atmosphere
- reduced slagging
- increased availability

Vattenfall

At the **Vattenfall** Tiefstack power station in Hamburg, the system has been fitted on both 252 MWel boilers. It analyses a front firing configuration with 6 burners and 3 mills each using 6 cameras and acoustic sensors in each case. The system controls the

- trim of airflows between burners of each level
- trim between secondary and tertiary air of all burners, and
- trim of airflows between the three burner planes

The results have been presented by Rosner, Röpell et. al. in VGB PowerTech 12/2008, "Efficiency Improvement on Hard Coal-Fired Steam Generators using a Self-Learning Video Based Optimization of the Air Distribution) and can essentially be summarized thus

- Eta steam generator: +0.3% λ = 1.22 to 1.15
- CO: -12%, NO_x -29 mg/Nm³
- residual C: -0.5% abs.

E.ON

At **E.ON's** Scholven site, the largest hard coal-fired power plant in continental Europe, 16 burners per boiler, mounted in a staggered frontal arrangement, are fed by 4 mills in each case. Each unit delivers 345 MWel and must cope with up to 12 different import coal mixtures. Marketing the fly ash had posed a challenge in the past, given that its suitability for use is highly contingent on residual C content. Thus, only ashes with less than 4.2% residual C can be sold to the construction industry as recyclate. Although quality is being improved and homogenized by mixing the various ash grades from all burners, major fluctuations and frequent residual C levels in excess of 5% had made the ash difficult to use.
The optimization solution has been installed in Unit C since mid-2007 and optimizes the fuel/air distribution per burner as well as across burner levels. Six camera sensors monitor 16 burners frontally. Using patented pattern recognition technology, unique features regarding ignition, burning and burn-out behaviour are thus extracted directly from the combustion chamber.
Four vibration sensors detect mill vibrations which are analyzed by a separate computer. These vibration data provide information on milling fineness and coal quality.
In addition, control system data on the combustion process are continuously read out via an interface. The system then correlates these data with optical features of the combustion chamber and with acoustic mill information, using neural network-based

software. The computed setpoint corrections are written to the control system via the interface.

Since July 2008, ash quality has been found to be significantly more uniform, with an up to 1% (abs.) reduction in residual C, depending on the fuel grade employed. The PiT Navigator is permanently active and provides an improved burnout in the load range between 960 and 1.200 tonnes/h of steam. Mr. Armin Wolke, Head of Production at the E.ON power station in Scholven, summarizes his experience thus: "The combination between flame analysis and model-predictive control system has proved very successful, reducing residual C by up to 1% abs., depending on coal quality. What is more, the boiler wall atmosphere has remained invariably good."
Marketing the fly ash has been greatly facilitated and rendered more profitable by the optimization drive. Ash from Unit C can now be mixed with ash from other units to compensate for their higher residual C values. Apart from making the fly ash more easily marketable, the plant's fuel efficiency has been enhanced. Investment costs have thus been recovered more quickly.
Despite initial scepticism, the system has convinced the operators through its performance. Tests have confirmed that the software adapts to new process conditions autonomously thanks to its self-learning capability
In a next step, it is intended to tap further optimization potentials with the aid of the system.

Various optimizations

In the context of diverse optimization contracts, the system has further demonstrated that neuroinformatic technology is capable of detecting correlations and delivering successful predictions which yield an improved boiler operating regime.

Summary and outlook

The vision of a joint digital analysis of mill and flame data, in conjunction with an optimizing control system which improves automatically through self-learning from its process experience so as to adapt independently to new process conditions, led to the development of a complex process optimization solution.
Today, 25 years after the emergence of this vision, the solution is fully developed and protected by around 80 patents. It has been implemented on six large-scale power station boilers and delivers the anticipated effect, i.e., meeting the demand for efficiency improvements, with flying colours.

Every new application of this optimization system on a new power station boiler will benefit the environment by saving resources while cutting CO_2 and NO_x emissions at the same time. The consumption of coal is typically reduced by 1% to produce the same electrical output. Hence, the use of this system on all coal-fired power station boilers in Germany would bring down CO_2 emissions by approx. the CO_2 output of all passenger cars registered in the *land* of Thuringia.

This record has also convinced GTZ (Deutsche Gesellschaft für technische Zusammenarbeit), the German Cooperation Enterprise for Sustainable Development, which subsidizes this technology in India and has committed funds in the middle six-digit range to supporting its success there.

The potential of this solution in the context of other optimization tasks has by now been demonstrated, e.g., in the cement making and chemical industries, as well as in flue-gas cleaning applications. But the system's capability to handle other complex optimization tasks does not stop there. It will show its merits wherever an adequate architecture of actuators and sensors is available in a process susceptible to efficiency improvement through the use of an optimization system.