Leaner, fitter, smarter

Optimizing the trade-off between profit, asset lifetime and emissions to improve energy efficiency in the power generation industry

Marc Antoine

Faced with the ever-increasing competitiveness of today's global markets, companies in the utility industry are constantly striving to optimize plant operation and lifecycle costs, and reduce emissions. They search for powerful diagnostic and optimization tools to identify performance deviations so that corrective action can be introduced early.

In addition, these tools should reduce the maintenance effort for all plant equipment, extend the life of critical capital equipment and increase the utilization of the existing asset base, thus improving total plant availability and productivity.

In electric power generation, ABB's OPTIMAX™ Plant Optimization systems give power plant managers a number of perspectives with regard to the efficiency and expected performance of assets such as boilers or turbines.

Power plant operators are under constant pressure to improve plant performance, availability and maintainability, reduce emissions and costs while delivering power at competitive market prices.

ABB is sensitive to these challenges and is aware of the customer's eagerness for a comprehensive solution. Providing a suitable solution has been made easier because technological advances in the areas of control and software engineering have led to the development of innovative plant optimization systems.

Accurately monitoring and predicting plant performance involves more than simply calculating the expected power and efficiency of the plant.

Today's systems are capable of taking the lifetime consumption of equipment into account so that different load profiles can be optimized. Hence, plant optimization systems are a "value-adder" because they can significantly increase the economic efficiency of a plant and reduce plant emissions.

ABB's contribution is the OPTIMAX™ Plant Optimization systems. These are decision-support tools which continuously assess plant condition and provide root cause analysis in case of deviations 1. The OPTIMAX™ Plant Optimization systems are at their most powerful when they are combined together so that true predictive maintenance and effective repair is performed before what could otherwise be a costly shutdown.

Some of the systems included in the overall OPTIMAX™ portfolio are described in the following paragraphs.

Performance monitoring

Before any kind of optimization and control decisions are made, plant managers need to know how efficient their plant and equipment is working. Regardless of a plant's age, the major portion of a power plant's lifecycle costs is attributed to fuel and operation, whereas maintenance represents most of the remaining costs. Minimizing these costs and improving predictive maintenance are the key objectives of the operation and maintenance staff.

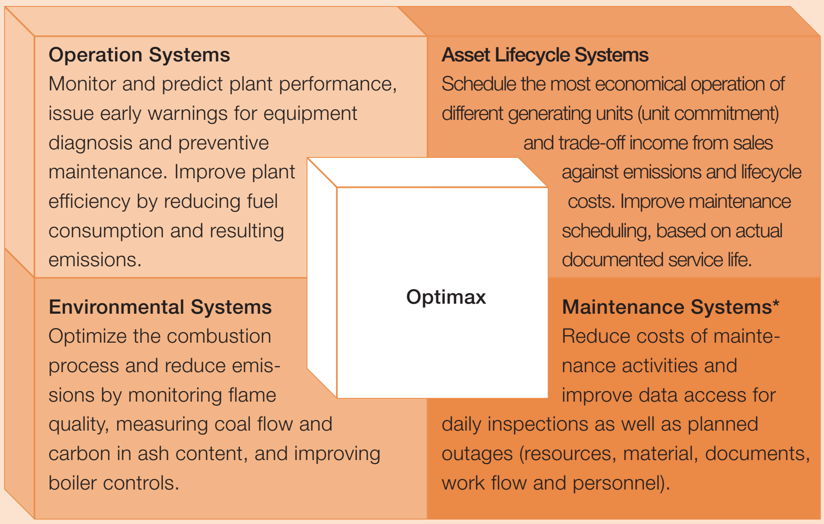
To help them achieve these objectives, OPTIMAX™ *Performance Monitoring* system is an application designed for performance monitoring of the plant and its equipment. It facilitates online or offline analysis of the process so that the user can determine how current operating conditions affect, for example, the plant heat rate and therefore plant fuel costs 2.

A system of this type is based on steady-state calculations and can run cyclically or on-demand. Its main task is to calculate deviations between *actual* and *expected* plant Key Performance Indicators (KPIs) at current operating conditions.

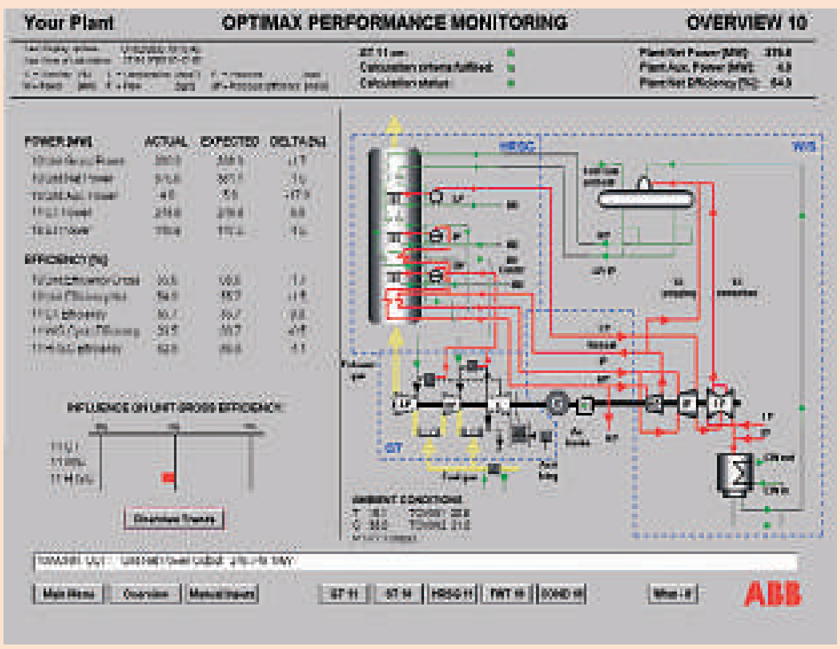
The task of accurately monitoring and predicting plant performance, however, involves more than simply calculating the expected power and efficiency of the plant. The calculation of detailed performance values (pressures, temperatures, flows, etc.) at several

1 Plant optimization systems within the Optimax™ solution suite.

*Maintenance systems are not covered in this article.



2 A typical OPTIMAX™ performance display.



hundred locations throughout the plant has become a standard requirement. Short- and long-term equipment degradation of individual components can only be recognized if deviations from the best achievable (expected) efficiency levels are clearly identified.

This can be achieved by using *Performance simulation models*. These are thermodynamic models which accurately simulate the performance behavior of the plant under varying ambient and different steady-state operating conditions. Such simulation models, as shown in 3, can be easily designed using the OPTIMAX™ *PowerCycle* tool to compute the expected plant equipment process values at current operation mode. The results are then used to determine the expected KPIs. As an additional benefit, PowerCycle can also be used for "what-if" calculations so that optimal operating strategies can be developed.

Unfortunately, measurement inaccuracies – caused by stochastic or systematic errors – are usually the reason why consistent mass and heat balances cannot be compiled for single components or the entire plant. Such balances can only be obtained by correcting the measured values in such a way that they do not contradict the relevant energy balances. The systematic computation of such corrections is known as *Data Validation* (or Data Reconciliation). In other words, Data Validation improves the reliability and accuracy of the performance calculations.

A precondition for this type of calculation is an exact model of the plant, such as the performance simulation model described above. A large number of measured values are therefore connected to this model in addition to the measured data needed to perform the simulation 4. When Data Validation is included, the simulation model not only provides a set of consistent thermodynamic balances, but it also allows for the identification of sensor failures, sensor drifts and/or loss of equipment efficiency.

Optimization strategies merely based on human know-how have become insufficient for companies operating multiple generation or co-generation units.

Resource optimization

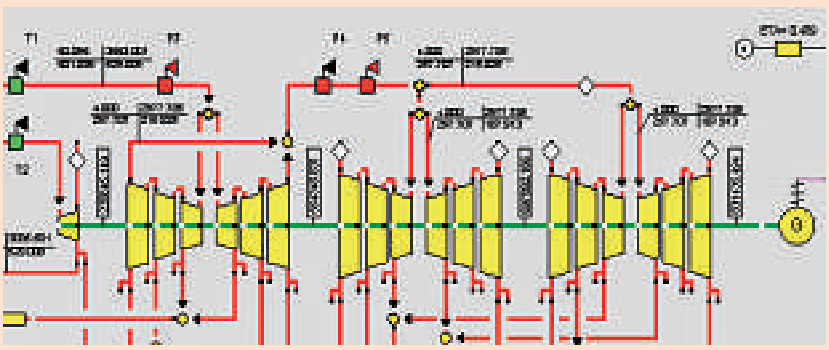
Power generation companies, municipalities, industrial power plants and desalination plants need a sound basis on which to trade energy on the open market. Optimization strategies merely based on human know-how have become insufficient for companies operating multiple generation or co-generation units.

The OPTIMAX™ Unit Commitment system combines fully developed asset and market models with the latest optimization techniques. This system can handle utilities with complex generation portfolios which are seeking to optimize their costs and energy generation, be it electrical or a combination of electrical and other forms of energy (heat, hydro, waste, etc.). 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. Using state-of-the-art numerical solvers, this application minimizes the total generation costs of a power company by scheduling the energy load between different units – known as Unit Commitment – to satisfy load demands in the most economical way.

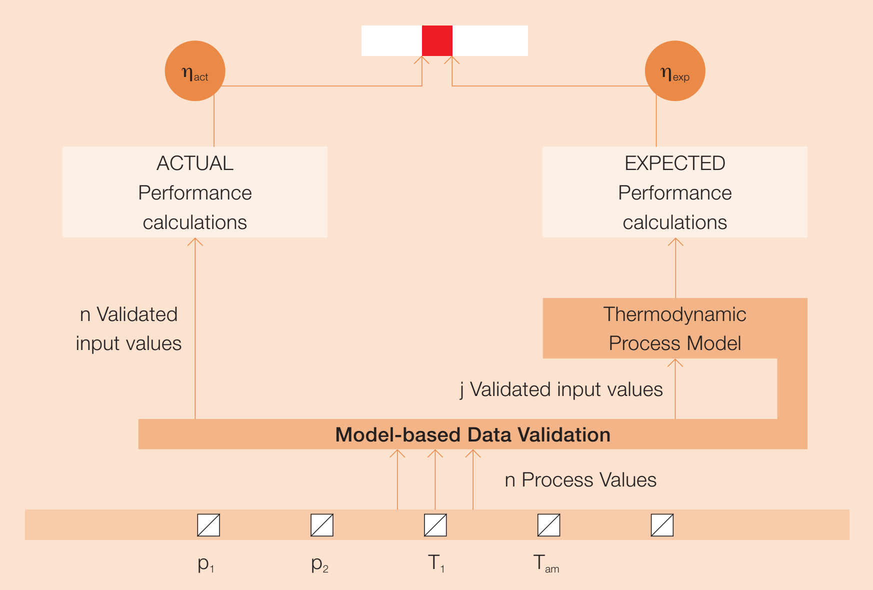
This optimization system typically runs in offline mode to determine the effects of certain what-if scenarios and train personnel in its effective use. It allows the analysis, planning and scheduling of multiple generation units over different time horizons, ie, from several hours to several months 5.

In general, when an optimizer determines the most economical load profile of plants based on generation costs and revenues from energy sales,

3 Detail of a PowerCycle plant simulation display.



4 Data Validation before doing performance calculations.



two important cost factors are still missing: those attributed to lifetime consumption and emissions.

Under the umbrella of Resource optimization, OPTIMAX™ *Lifecycle Optimizer* [1] addresses the influence of operating modes on the full cost of running a power plant and includes this in an economic optimization model. The optimization scope includes energy sales, production and emission costs, as well as plant ageing based on lifecycle models. It uses parameters such as power prices and emission credits or penalties (which will be reduced to mere commodities in the future) calculated against long-term maintenance costs to optimize economic plant performance. The advantage of the Lifecycle Optimizer is its ability to include plant ageing models to find the optimal operational strategy between maintenance outages. This solution clearly shows its advantage in terms of Return-on-Investment and profit increases of several percent.

The new emission regulations will have a substantial impact on the profitability of today's power plants

The new emissions regulations, in particular within the EU, will have a substantial impact on the profitability of today's power plants. If a plant emits less than the level of its emission allocations, it can sell the additional permits to others that may have emitted more. If a plant emits more, then it needs to purchase additional permits or pay a penalty. The added value of the Lifecycle Optimizer is that it can assist plant managers in finding a trade-off between short-term profits and long-term asset costs, especially when operating under environmental constraints.

Energy efficiency in power generation, distribution and consumption is fast becoming a priority in the global battle against greenhouse gas emissions. ABB's *Combustion Optimization* solutions will continue to help power plant operators around the globe to improve operating efficiency.

Combustion optimization

The combustion processes in gas- or fossil-fired power plants are very complex. OPTIMAX™ Combustion Optimization system, however, helps power plant managers optimize their combustion process and reduce emissions by: improving boiler controls; monitoring flame quality; and measuring coal flow and carbon-in-ash 6.

A unique characteristic of the software is its ability "to learn" and "predict" trends, resulting in reduced response times to changing conditions.

Improving boiler controls

Before energy market liberalization, the large fossil-fired power plants were mostly operated at base load with few or no plant shutdowns during the year. Today an increasing number of these plants often operate at part load, and frequently shut down because of market prices and trading decisions. As a consequence, the issues of startup costs, energy losses, and emission control have gained in importance.

This is where ABB's *Dynamic Optimizer* application comes in. With this tool, solving optimal control problems in closed-loop mode is possible. It can take existing constraints into account as an inherent part of the control variables. This "dynamic" capability is an improvement when compared to conventional solutions which often require extensive modifications to the control system functions when constraints change.

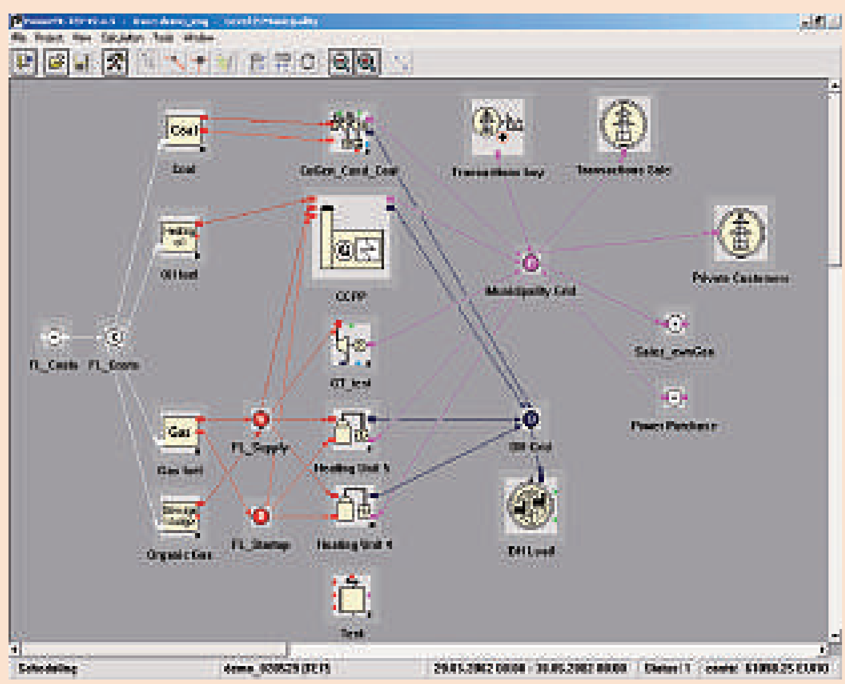
An example application of where Dynamic Optimizer has been implemented is the *BoilerMax* solution for the optimization of a boiler start-up [2]. BoilerMax was developed by ABB to enable all of the advantages of uniting model-based closed-loop control and IT to be applied to steam generators in large power plants. For a typical 700 MW_{el} coal-fired plant which frequently shuts down during the year, this solution minimizes start-up times and reduces emissions with total cost savings of up to 10 percent.

Monitoring flame quality

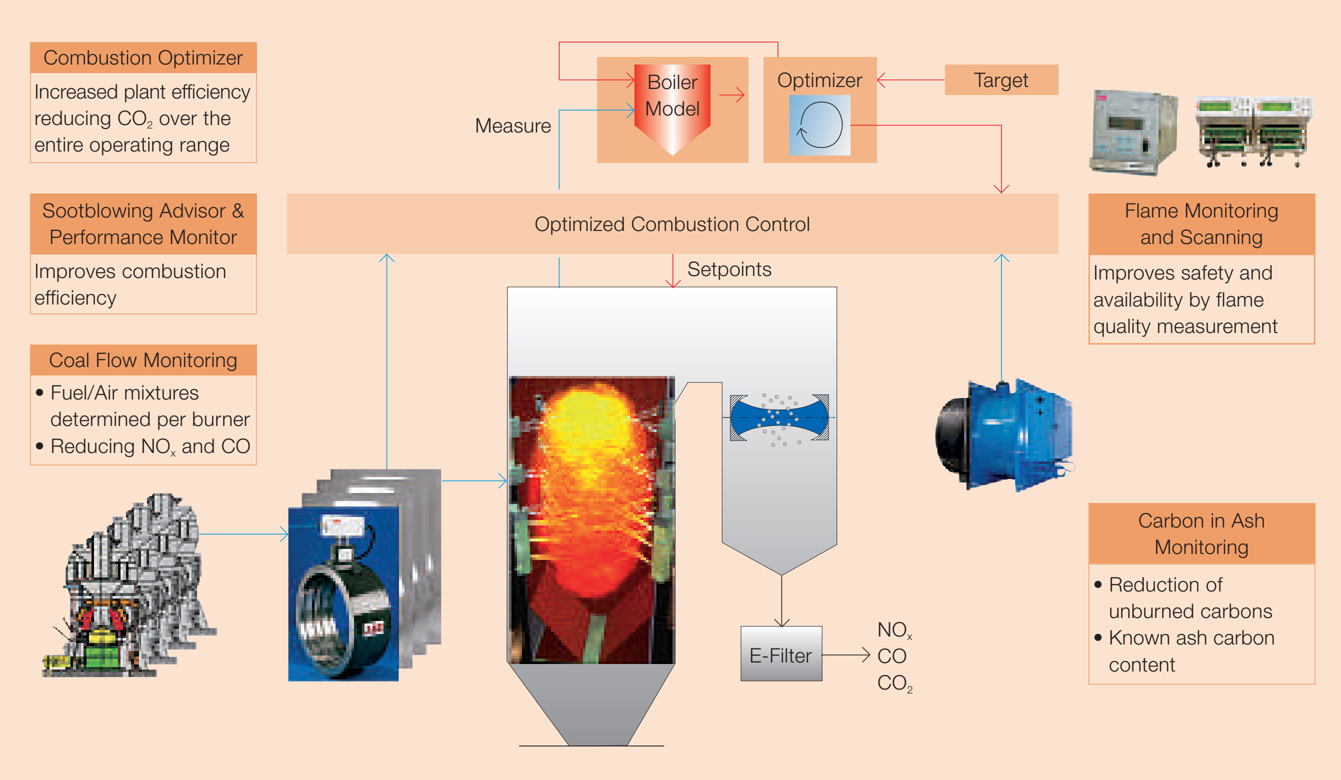
Flame scanners are a crucial part of a combustion safety system. Their primary function is to identify potentially dangerous "flame-out" conditions where ignition has ceased and the continued addition of fuel could cause an explosion. Because of their importance, flame scanners must be extremely reliable and rugged to measure the quality of the signal and provide an indication of changes in the burner flame. These quality values act as a barometer, forecasting when a burner flame-out is likely to occur, thus indicating unsafe conditions and problems.

ABB's flame scanner and igniter technology has been reliably in use for many years on boilers and gas turbines. The development of these instruments and their corresponding

5 A typical OPTIMAX™ optimization configuration window.



6 Combustion optimization.



software solutions has allowed plant owners to continuously reduce emissions and to follow the path of environmentally friendly operations.

With the advances in the fields of controls and software engineering, the use of process simulation has become a crucial element for assessing plant performance.

Reducing emissions by measuring coal flow and carbon-in-ash

OPTIMAX™ model predictive control (MPC) solutions can optimize boiler efficiency and help reduce NO_x emissions 7. It is a generalized multi-variable, dynamic controller and optimizer and uses dynamic feedback to update the models. This system characterizes and quantifies the effects of operational parameters on the efficiency and emission of a power generation unit [6].

Critical variables influencing the heat rate are excess O_2 and the exhaust gas temperature. On the other hand, NO_x is strongly influenced by the flame temperature. Heat rate and NO_x models are developed from test and historical data utilizing inferential models. The models are then used to continuously determine the combination of set points and/or biases to achieve the most economical operating condition. Past projects have reached up to 0.75 percent efficiency improvement while maintaining emission limits, thereby providing a return on investment of between 1 to 2 years.

A typical coal-fired power plant can produce up to 500 tonnes of fly-ash in a single day. If this fly-ash contains too much carbon (unburned coal), it must be disposed of - usually in large costly landfills. By employing ABB's *Carbon-in-Ash* monitor with its closed-loop control, utilities can now produce high quality, low carbon fly-ash which can be used as a primary constituent of gypsum wallboard and blended cement. This non-extractive monitoring system incorporates advanced microwave technology for the continuous and accurate measurement of carbon in fly-ash. In fact it is the only measurement system of its kind that can be integrated into a closed-loop optimization control system [3].

The use of fly-ash in cement production also results in a significant reduction of harmful emissions. But this isn't the only advantage for a utility: improved coal combustion and fly-ash sales from a large power plant can yield an annual return of up to $1 million.

Heat exchanger surfaces inside boilers continuously degrade due to fouling caused by soot. Because of this, it is necessary to use soot blowing cleaning techniques to recuperate these losses as much as possible. Although soot blowing is a necessary cleaning procedure for boilers, it temporarily decreases boiler efficiency. When this process is optimized, however, long-term plant performance is increased.

The OPTIMAX™ *Soot Blowing Advisor* calculates online sectional surface cleanliness values as well as the temperature of gas entering each boiler section. The model is configured and tuned to unit-specific boiler data. The results obtained from this module support plant operators and engineers in optimizing the current plant soot-blowing scheme, and can translate into significant fuel savings.

Parameter estimation for diagnosis and optimization

With the advances in the fields of controls and software engineering, the use of process simulation has become a crucial element for assessing plant performance. The usefulness of such systems, however, strongly depends on the ability of the simulation model to represent the plant equipment properties. Having accurate models representing a large range of operating conditions is a very challenging and largely unsolved problem. Indeed, even in cases where the technical processes are well understood – as is the case in power plants – the models remain parameterized by a number of unknown or hard-to-measure quantities such as heat transfer coefficients, thermal inertias, and turbine and compressor characteristics.

Parameter estimation is a technique that has produced powerful modeling methods and tools (based on collected data) that are particularly useful in power plant optimization. For example, parameter estimation is used to estimate the natural degradation in gas turbine compressors and to optimize online and offline compressor washing cycles [4]. When compared with traditional scheduling methods, the resulting maintenance schedules clearly show the achievable economic benefits, especially for plants that are in continuous operation. In addition to this, the method can also be used for improving equipment *diagnosis* and quantifying the accuracy – and hence the *risk* – of the diagnostic results.

For example, the OPTIMAX™ *Gas Path Diagnosis* tool determines the probability of compressor fouling and turbine erosion, thus improving preventive maintenance actions and reducing overall costs.

Increased operator efficiency can be directly translated into cost savings in the form of optimal plant operation.

The same MPC based technology for optimization used in combination with the parameter estimation toolbox has been successfully applied by ABB in other industries. In the cement industry, for example, this approach has generated thermal and electrical energy savings of up to 5 percent as well as significantly reduced emissions and maintenance costs [5].

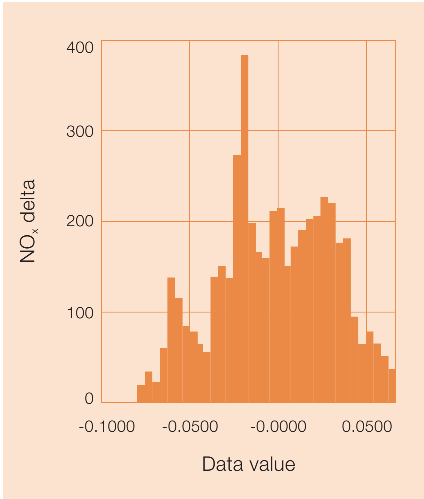
Operator training simulators

The best power plant operators know when to react, what to do, and how to do it. This ability comes from years of operating the plant in a variety of normal and abnormal operating conditions, as well as from knowledge about the process and the control system. This ability comes from either years of experience and training, or perhaps it is a combination of both.

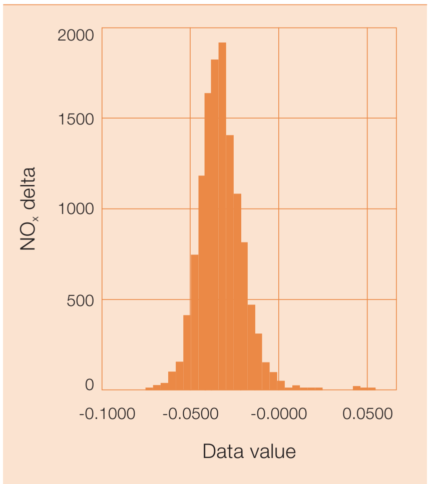
ABB's Operator Training Simulators (OTS) are used to train new plant operators, and refresh and deepen the knowledge of experienced plant personnel. Ultimately, increased operator efficiency can be directly translated into cost savings in the form of optimal plant operation under all conditions, damage limitation, decreased down time and decreased production loss.

7 Reduction of NO_x emissions variability through optimized combustion control.

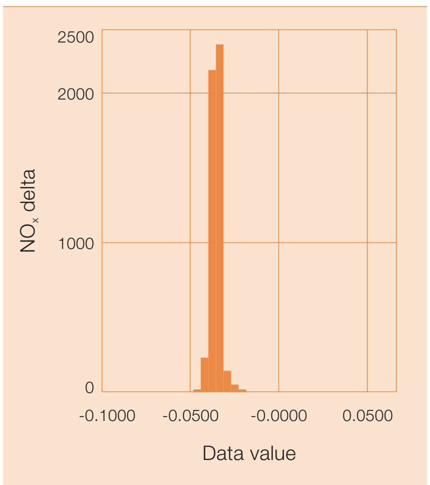
No Control on NO_x rate



Open loop control on NO_x



Closed loop control (SP mode) on NO_x



Customer benefits

If a plant is run on condition-based maintenance, where outages are not planned at regular intervals but are dependent on the state of the plant, the success of this strategy depends on the quality of the plant condition assessment. Tools for the continuous assessment of a plant's condition enable the early detection of degradation or emission violations, as well as the validation of measured data and sensor quality. Of course this helps the plant staff reduce fuel consumption and emissions, but even with a very precise plant state assessment there is room for optimization in this approach.

Performance monitoring, optimization techniques and risk assessment are central components of today's plant optimization systems. Their main task is to reduce negative surprises by quantifying performance problems and reducing emissions.

The decision makers use these systems to improve predictive maintenance, extend asset lifecycles and, most of all, to meet financial targets.

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