Model-based Boiler Control and Optimization using Soft Sensors in a modern Utility Boiler

Dr.-Ing. Francesco Turoni
Introduction

Achieved benefits

Model-based control and optimization

Soft sensors

Model predictive control

Results

Summary
Why do you focus on combustion and boiler operation?

Because this is where the overall process is least perfect.
There are a number of uncontrolled and unidentified variables that greatly influence combustion performance. These influencing variables include
- mill operating conditions (primary air temperatures, air/fuel ratios, flows, grind, and moisture),
- secondary air non-uniformity (air register settings, forced draft fan bias, and windbox pressure differential),
- coal variability, etc.

*If you can’t measure it, you can’t control it. If you can’t control it, you can’t optimize it. We want to close this evident gap.*

Why is the run for intelligent diagnostics and optimisation?

*It is not just a case of intelligent diagnostics being 'nice to have' for companies, but, nowadays, more a strategic necessity to help stay ahead of the competition.*
Continuous optimisation permanently finds the best economic and technical trade-offs without ever stopping. It is as effortless as breathing.
Make it an arduous exercise and it will be forgotten more than once. Human nature is just too forgiving to aspects of comfort.

The solutions we propose pay for themselves in less than a year.
Compared to conventional upgrading the capital costs appear negligible.
Moreover, the entire process will now seamlessly integrate into any best practices or TQM approach.
Achieved benefits
Benefits quantified

Plant

Unit size 630 MW
Lignite LHV 10,300 kJ/kg
PLF 88.5 %

Reference

Coal flow 660 t/h
O₂ excess 4.0 %
LoI ref 2.9 %
T Boiler Exit, ref 199 °C
η Boiler, ref 86.66 %

Optimisation

Coal flow 655 - 657 t/h
O₂ excess 3.2 %
LoI opt 1.8 %
T Boiler Exit, opt 191 °C
η Boiler, opt 87.10 %

Savings

Δ Coal p.a. > 23,000 t
Cost per tonne* 26 EUR
Annual savings ~ 600,000 EUR

Δ CO₂ p.a. > 27,300 t
CO₂ Certificate 20 EUR/t
’Carbon benefit’ ~ 550,000 EUR
Total benefit p.a. 1,150,000 EUR
Benefits and deliverables

**Benefits ...**

- EUcontrol-boiler is an optimal cost-value ratio option for producing sustained boiler operation under desired conditions (low NO\textsubscript{x}, reduced slagging, high efficiency)
- No modification of plant DCS system required
- Highly adaptive, automatically adjusting to changing situations
- Multivariate target optimisation (low NO\textsubscript{x} AND low fouling AND high efficiency)
- Customisable to individual plant requirements

**... leading to a new value proposition**

- Consideration of different operational objectives (technical, commercial, environmental)
- Offering an attractive means to upgrade older boilers at low cost
- Straightforward implementation at lowest risk (model based)
Model-based control and optimization
Integrated boiler management

EUcontrol-boiler

Advanced Diagnostics & Boiler operating data (DCS, data base)

Measurement data analysis & Adaptive system identification

Optimised boiler operation

Over fire air

Coal

Primary air/Coal feeder

Mill
Optimization suite EUcontrol

System set-up at plant

- Boiler
- DCS
- Sensors, Actuators
- Interfaces for Data Exchange
- EUcontrol
- Adjust Optimization Goals and Constraints
- Monitor Optimizer Information
- Define Optimization Goals, Operational Constraints, System Parameterization
- Advanced Operator
- Operator
- Data Archive
- Record Process and Operational Data
- Provide Optimizer Reports
- Management
- Provide Process Data
- Optimal Set Points
- Data Exchange
The plant behaviour is predicted with an identified process model. An optimiser calculates the best possible combination of inputs.

Hard and soft constraints can be equally considered. Preferential adjustment of set-points is possible if the degree of freedom is sufficient.
Data structure

Plant model

INPUT (u)

1. Manipulated variables
   - Primary air (1...8)
   - Coal hopper (1...8)
   - $\Sigma$ Secondary air
   - OFA 1
   - OFA 2
   - $O_2$ Excess

2. Measured (dist.)
   - Output power
   - Soot blowers

3. Unmeasured (dist.)
   - Coal quality

OUTPUT (y)

4. Constraints
   - FD fan pressure drop
   - Mill temperature
   - Mill arrangement

- $NO_x$
- $T_{FEGT}$
- $CO$
- $\eta$
- $\perp \sigma_T$
- $T_{Mill} (1...8)$
Optimization suite EUcontrol

Model-based development (RCP, HiL)

- Boiler process model
- Adjust Optimization Goals and Constraints
- Monitor Optimizer Information
- Define Optimization Goals, Operational Constraints, System Parameterization
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- Advanced Operator
- Provide Process Data
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Goals and Constraints
Operator
Data Exchange
EUcontrol
Management
Soft sensors
Advantages

- Reduced measuring hardware requirement
- Inherent sensor validation, fault detection and diagnostics
- Provision of real-time data for advanced control requirements
- Allowing straightforward what-if analysis
Secondary air flow „measurement“ using soft sensor

Secondary air damper characteristic

- Air flow [Nm³/s]
- Damper position [%]

- air flow (soft sensor)
- measured air flow
- damper characteristic measured
- damper characteristic modeled
Model predictive control
Model predictive control

MPC with adaptive process model
Model predictive control

**Strategy**

- Prediction horizon $H_p$
- Control horizon $H_S$
- Optimization of control action within control horizon under consideration of system development within prediction horizon resp. cost function:

$$I = \sum_{H_p} \sum_{Ziele} w_{1,i} (y_i - r_i)^2 + \sum_{MV} w_{2,i} (\Delta u_i)^2 + \sum_{MV} w_{3,i} (u_i - r_u)^2 + \sum_{RB} w_{4,i} (\max(y_i - M_i, 0))^2$$

**Diagram:**

- Setpoint
- Reference trajectory
- Control variable
- Manipulated variable
- Time
- $t \rightarrow t + H_S \rightarrow t + H_p$
Model predictive control

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Model predictive control

Real time visualization

- Visualization of
  - Historical data
  - Prediction horizon
  - Target values

Predicted effect on the control variable (green line) as opposed to unmanipulated operation (red line)
EUcontrol User Interface

Controls at fingertips
Results
Optimisation - results

Result of optimised settings (optimisation goal)

- **NO\textsubscript{x} control**
- Significant improvement of operation conditions while reducing slagging and fouling
Optimisation results

Result of optimised settings (optimisation goal)

- CO control
- Significant improvement of combustion quality
Optimisation: λ operating mode

Enhance boiler operation - O₂ and air-fuel ratio

- EUcontrol activ 29/4/2010 - 12/5/2010
- EUcontrol not activ 2/2/2010 - 15/2/2010
- standard deviation EUcontrol aktiv
- standard deviation EUcontrol not activ
Optimisation: Fuel-air staging mode

Process stabilization

Air/fuel ratio 'lambda'
- Range of all active mills
- Average
- Targeted area
- Average

Hopper speed
- Range of all active mills
- Targeted area
- Average
Optimisation: $\lambda$ operating mode

**Improve NO$_x$, CO, O$_2$ and damper positions**

- **Targeted area**
- **Average**
- **CO**
- **O$_2$ set point**

**Separator**
- **Average**

**Overfire air 1**
- **Average**

**Overfire air 2**
- **Average**
Steps to success...

- Site familiarisation and review of existing plant equipment
- Identify performance objectives
- Identify additional equipment requirements
- Review of available data and data quality
- System identification using available data
- Combustion parametric testing using Design of Experiments
- Build prediction models for control/optimisation
- Build process/plant model for model-in-the loop testing (hardware-in-the loop)
- Operate in advisory mode
- Extend to closed loop

Typical project time is 4 – 5 months
**Summary**

**Benefits**

- Improved efficiency (0.3 to 1%)
- Reduced O$_2$ (- 5 to - 10%)
- Reduced NO$_x$ and CO emissions (- 5 to - 15%)
- Reduce slagging and fouling, limit soot blower operation
- Reduced LoI
- Less material stress in furnace due to more even temperature distribution
Thank you for your attention

For more information, please visit us at booth G100