Neural networks versus physical models for control solutions in coal fired power stations

Fossil Fuel Foundation
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## Agenda

- **Challenge**
- **Solution**
  - Combustion Optimizer
  - Neural Networks
  - Physical Models
  - Comparison
- **Achievements**
- **Benefits**
Challenge
Challenge

Consideration of different operational objectives

- Process stability under varying coal qualities
- Severe slagging and fouling
- Incomplete combustion
- Automation of operational goals

→ Necessity for system control & optimization
Solution
Solution

Combustion Optimizer

- Set point optimizer on top of the existing DCS
- Three different approaches:
  - Physical models
  - Neural Networks
  - Hybrid model
- Integration of the model/network into an optimization function
General optimization scheme (Model/Network/Hybrid)

Solution

- Boiler
- DCS
- Sensors, Actuators
- Advanced measurement technologies
- Optimizer
- Measurement Data
- Optimal Set points
- Process Data
- Operator
- Monitoring
Neural Networks

- Computational models inspired by central nervous system
Solution

**Neural Networks**

- Single Neuron and weighing function

Components of one unit

Weighing function between two units
Solution

Neural Networks

- Example: logical operator

Solution for AND

Solution for OR

Solution for XOR
Solution

Neural Networks

- Finding the maximum

best adaptation
global maximum

local maxima
Solution

Neural Networks

- Small change in any weight (or bias) causes a small change in the output

\[ \omega + \Delta \omega \]

\[ \text{output} + \Delta \text{output} \]
Solution

Physical Process Models

- Process knowledge is subsumed in a model
- Based on physical principles:
  - Conservation of mass
  - Conservation of energy
  - Conservation of momentum
- Parameters are fitted into measurement data
- Model is integrated into optimization function
Solution

Physical Process Models

- Example: Model-based air measurements
Solution

Hybrid Models

- Combination of Physical Process Model and Neural Network
- Known dependences as basis for the function (e.g. O2 vs CO)
- Left variables are tuned by Neural Network
# Solution

## Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>Physical Model</th>
<th>Neural Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicable to unknown situations</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td>Extrapolation</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Re-Usability</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Extendability (e.g. measurements)</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Explainability, Validation</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Training of operational staff</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>
Neural Networks
- High sensitivity to outliers in measurement data
- Long training period

⇒ Neural Networks can be used, but it takes a long time to adjust them

Physical models
- Process know-how required
- Robust
- Very good extrapolation
- High reusability

⇒ Works good in the power plant sector
Achievements
Achievements

Example Neural Networks

- NOx Reduction

Annual Mass & Avg Emissions

1992 Emissions 0.620 lbs/mmBTU’s
35000 Tons of NOx

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Achievements

Example Physical Process Models

- Optimized combustion process: CO Reduction at same oxygen level
- Very fast time to market: 4 Months
Benefits
Benefits

Model-based approach

- No cost extensive retrofits
- Add-on solution, seamless integration into DCS
- Improved efficiency
- Fast time-to-market
Thank you!

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