Advanced Control and Optimization of Power Plants

OPTIMAX® Suite for Real-Time Optimization

- Fleet-wide Optimization
- Unit and Component Optimization
- Performance Monitoring
- Combustion Instrumentation
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FLEET-WIDE OPTIMIZATION

- Unit Commitment
- Economic Dispatch
- Emissions Control
- Hydro Scheduling
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FLEET-WIDE OPTIMIZATION

- Automatic Generation Control
- Load Sharing
- Coordinated Frequency Control
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UNIT AND COMPONENT OPTIMIZATION

Using Advanced Process Control (APC) to
- Improve Stability
- Reduce Variability
- Optimize

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ABB Power Generation
North America
Slide 5
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UNIT AND COMPONENT OPTIMIZATION

- Boiler Start-Up Optimization
- Unit Response Optimization
- Coordinated Boiler-Turbine Control
- Model-Based Runbacks

- Combustion Optimization
- Advanced Temperature Control
- Sootblowing Advisor

- Faster Start-Up Times
- Faster Ramp Rates
- Reduced Emissions
- Improved Heat Rate
- Increased Capacity
Optimized Scheduling of Power Generation

- Short-Term Optimization, time span from hours to days
- Uses mathematical techniques such as Linear Programming (LP) and Mixed Integer Programming (MIP)
- Optimize procurement and generation based on demand forecast
- Minimize startup and operating costs
- Optimization of hydro reservoirs
- Compare different scenarios, and adjust the generation schedules accordingly
- Provides decision support for users or automatically dispatches generation targets to unit control
Pohjolan Voima (PVO) is a privately owned group of companies in the energy sector, which produces electricity and heat at cost for its shareholders in Finland. The Group also develops and maintains technology and services in its sector. PVO-Pool Oy, a subsidiary of Pohjolan Voima Oy, is responsible for the optimal power procurement and the related electricity trade for Pohjolan Voima Group." (www.pvo.fi)
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UNIT AND COMPONENT OPTIMIZATION

How APC Improves Performance

Improved Control Reduces Process Variability
Reduced Variability Allows Operation Closer to Optimum Constraints

Operating closer to limits reduces operating costs, increases production, and/or reduces emissions & wastes, all of which improve profits.
**ABB uses MPC = Model-Predictive Control:**

- Due to the many constraints and complex interactions, power plant APC and optimization is well suited for the multi-variable model-predictive controller (MPC).

- The knowledge of dynamic process behavior is contained in the models of the MPC - i.e. it “knows” the dynamic behavior and all the interactions between the process quantities.

- The MPC controller evaluates model output response to model input changes, predicts immediate future process behavior, and controls all the variables at the same time, in a coordinated and anticipatory fashion. Examples of COS models:
  - NOX prediction from Overfire Air (OFA) moves
  - NOX prediction from mill bias moves
  - NOX prediction from burner tilt moves

- This is demonstrably superior to traditional control (e.g. PID control), where each controller has one input and one output and process dynamics are unknown by the controller.
Step Increase in Boiler Coal Input

Dynamic Models and Interactions of the MPC

Model Outputs

Boiler Consumed Air Increases
Boiler Steam Flow Increases
Temperature Increases
Steam Pressure Increases
Model Identification example - NOX vs. Overfire Air

NOX Predicted from Overfire Air Moves

Actual NOX

Predicted NOX

NOX Predicted from Overfire Air Moves
Model Identification example - NO\textsubscript{X} vs. Mill Biases

Implementing MPC Solutions

- NO\textsubscript{X} Predicted from Mill Bias Moves

- Predicted NO\textsubscript{X} vs. Actual NO\textsubscript{X}

NO\textsubscript{X} Predicted from Mill Bias Moves
Model Identification example - NOX vs. Burner Tilts

- **Actual NOX**
- **Predicted NOX**

NOX Predicted from Burner Tilt Moves
MPC Coordinates the Control of Multiple Variables Simultaneously

Typical Power Plant Constraints:
- Maximum Live Steam Temperature
- Maximum Live Steam Pressure
- Maximum Reheat Temperature
- Minimum Flue Gas $O_2$ Content
- Maximum Opacity
- $NO_x$ Constraint
- Condenser Vacuum
- FD Fan Capacity
- ID Fan Capacity
- Windbox Pressure Differential
- Metal Temperature Gradients

In a complex optimization solution, it is necessary to handle multiple controls & constraints simultaneously!
Boiler startup optimization

Features:
- Non-linear, Model Predictive Control (NMPC)
- The boiler model can be identified using measured data during startup phase
- Parallel calculation of setpoints for fuel, superheater and reheater steam temperature and pressure
- Explicit consideration of the thermal stress of thick-walled components (controlling temperature differences)

Benefits:
- Equipment protection
- Shorter startup time reduces fuel consumption
- Faster load response to load dispatcher, better position for energy trading
- Possibility for earlier warm-up of steam turbine and grid synchronization
Traditional startup procedure (dotted lines): Conservative startup to stay within design limits

Optimized startup:
Exploitation of design limits for more efficient process control

- Based on process model
- Predictive coordination of multiple variables
- Online optimization in real-time

Technology: NMPC (Nonlinear Model Predictive Control)

Typical 10 to 20% savings possible
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Boiler startup optimization – achieved benefits

Later increase of fuel, reduced HP bypass opening → 19% less fuel

Later development of thermal stresses
Combustion optimization

- Combustion Optimization is an APC application that automates many combustion control actuators that are normally controlled manually.
- The primary objective of COS is to improve heat rate and lower emissions.
- COS works with base DCS controls.
- COS works with many actuators not tied to feedback in the DCS and also biases DCS PID setpoints.
Combustion optimization

LEGEND

- MV: Manipulated Variable
- CV: Constraint Variable
- FF: Disturbance Feed Forward

Combustion optimization
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Combustion optimization – NOx Reduction (step 1)

As limit is lowered, more actuators help out:

- OFAD and Aux Air reach limits
- Aux Air bias -5 to 20%
- OFAD 0 to 100%
- WindBox ΔP -1 to 0.5

All actuators push back toward their soft targets
Combustion optimization – NOx Reduction (step 2)

As limit is lowered, more actuators help out:

Tilts and Elevation increase effort after air variables reach limits

East Tilt -5 to 15
West Tilt -5 to 15
Mill Elev -10 to 10
Combustion optimization – $O_2$ balancing, Heat Rate

- Perfect $O_2$ balancing while controlling NOx and minimizing reheat spray
Example: Boiler-Turbine optimized control

MPC VARIABLES:

**Manipulated Variable**
- Fuel Demand

**Controlled Variable**
- Steam Flow
- Generator MW
- Spray Flow

**Process Variable**
- Steam Flow
- Steam Pressure
- Steam Temperature

**Constraint Variable**
- ID Fan Demand
- ID Fan Current
- FD Fan Demand
- FD Fan Current

**Stoichiometric Air Flow**

**Example:** Boiler-Turbine optimized control
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**MPC** Tightens Control of MS Temperature & Pressure

Reduce Variability & Increase Targets

Improve heat rate and capacity
Energy Efficiency and Performance Assessment

Detects power plant degradation for lower energy costs, higher reliability, and optimized maintenance

**Features**

- Computes actual plant performance using ISO, DIN, IEC, and ISO performance test standards
- Compares actual performance to the performance expected under similar operating conditions
- Utilizes rigorous component models for performance prediction
- Models include boilers, turbines, pumps, fans, compressors, chillers, etc.
- Quantifies the observed degradation in terms of additional operating costs, or lost revenues
Benefits

- Earlier detection of mechanical problems, preventing development of more serious damage
- Optimal maintenance scheduling
- Prevention of unscheduled shut-downs
- Accurate and up-to-date component models available for optimization
- Actual performance of the plant depicted, rather than the changes in operating conditions
Cost Calculations

- Non optimized Operation is mirrored by Cost Deviations
- Focus to Problems according their relevance of Costs
- Higher Efficiency
- Better Cost Control
Combustion Instruments

Coal Flow - monitoring

Features
- On-line Pulverized Flow (PF) measurements of:
  - Absolute PF velocity
  - Burner PF split
  - Relative PF loading (concentration)
  - Mass flow rate, computed for each line, from split, but requires external total mass input (mill feed rate or similar)

Benefits
- Measurement across total cross section
- Non-intrusive, low maintenance
- Virtually unaffected by roping
- Tolerant to poor upstream flow conditions
- No need for on-site calibration, unaffected by changes in coal type and moisture content
- Saves PF sampling cost
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### Combustion Instruments

**Carbon In Ash - monitoring**

**Features**
- Online microwave measurement of unburnt coal in boiler backpass
- High accuracy
- Low maintenance
- Independent of coal quality and unit load

**Benefits**
- Detection of arising problems with
  - Burners
  - Air adjustment / distribution
  - Mills
- Improves ash quality
- Feedback or feed-forward signal for APC solutions
Combustion Instruments

Flame Scanners

Features
- Detects individual flame presence
- Provides flame quality index
- Continuous data to any plant control system via standard interfaces
- Individual flame raw signal for flame analysis and burner diagnosis

Benefits
- Improve safety, reliability, reduce downtime
- Feedback or feed-forward signal for APC solutions
Three-Phase Delivery Process

**Phase I**
- **Objective:**
  - Identify opportunities and solutions
  - Estimate benefits
  - Justification
  - Establish Baseline
  - Proposal

**Phase II**
- **Objective:**
  - Engineering of the solution
  - Commissioning
  - Training

**Phase III**
- **Objective:**
  - Verification of savings
  - Sustaining the results

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Conclusions

- **ABB** can deliver a full scope of Energy Management solutions to the Power Industry
- **ABB**’s Energy Management portfolio consists of different layers of instrumentation, control and optimization solutions
- Three-Phase Delivery Process
- System-approach → Coordinated solutions between different sub-systems
- Multivariable Model Predictive Control (MPC) as underlying technology for advanced control
- Benefits:
  - Better plant stability and availability
  - Improved agility (faster start-up times and ramp rates, increased capacity, and reduced stable minimum loads)
  - Higher plant efficiency
  - Reduced emissions
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