IMPROVING COAL-FIRED PLANT PERFORMANCE THROUGH INTEGRATED PREDICTIVE AND CONDITION BASED MONITORING TOOLS

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2021 Annual Project Review Meeting

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Presentation Overview

- **Project Information**
  - Project Team
  - Project Goal and Objectives

- **Background**
  - Microbeam’s Fireside Performance Indices
  - Microbeam’s Combustion System Performance Indices (CSPI) Program

- **Accomplishments**
  - CoalTracker Algorithm Development and Testing
  - Combustion System Performance Indices Algorithm Development and Testing

- **Opportunities for Plant Improvement and Cost Savings**

- **Next Steps**
Project Team

- **Technical Team:**
  - Microbeam Technologies Inc.
  - University of North Dakota
    - Institute of Energy Studies (IES)
  - Rochester Institute of Technology
    - Department of Software Engineering

- **Funding Support:**
  - U.S. Department of Energy, National Energy Technology Laboratory
  - Otter Tail Power’s Coyote Station
  - North American Coal Company
  - Great River Energy

- **Project Support:**
  - Energy Technologies Inc.
Project Information

Goal
Demonstrate at a full-scale coal-fired power plant the ability to improve boiler performance and reliability through the integrated use of condition-based monitoring (CBM) and predictions of the impacts of coal quality on boiler operations.

Project Period
January 1, 2018 – December 31, 2021 (4 Years)
Testing Sites

**Primary site: Otter Tail Power’s Coyote Station**
- Cyclone Fired Boiler
- MW – 450
- Fuel – ND Lignite
- Daily fuel delivery – 7000 - 12000 tons of coal – 2.5 million tons of lignite annual consumption – Mine mouth plant

**Secondary Site: Great River Energy’s Coal Creek Station**
- Pulverized Tangential Boiler
- MW – 550 (2 Units)
- Fuel – ND Lignite
- Annual fuel delivery – 7.5 - 8 million tons of coal – Mine mouth plant
Project Overview

CoalTracker Algorithms

Coal Mining/Processing
- Coal - stock piles of varying qualities
- Full Stream Coal Analysis - Moisture, H, V, S, ash composition
- Coal Tracker
- Bunkers/pulverize/ crusher
- Properties of coal delivered to each burner - coal flow
- Coal/ash Properties Database (10,000 samples)

Combustion System Performance Indices Algorithms

Boiler Operations
- Soot blowing cycle
  - Temperature, Heat flux
- Transport to Convective pass surfaces - Temperature, Burner lift
- High temperature fouling - Silicate based Erosion/Corrosion
- Entrained Ash (gas, liquid, or solid)
- Transport to water wall
  - Temperature, Heat flux
- Low temperature fouling - Sulfate based
- Ash Collector - Ash formation and partitioning during combustion
  - System design/geometry and boiler operating parameters, air flow, temperature
- Bottom ash or slag
- Wall Slagging
- Soot blowing cycle
  - Temperature, Heat flux
- Particulate and acid gas removal

Neural Network - Training and learning for selected predictions - Manage impacts of coal properties and boiler operations
Accomplishments

- **Database Development**
  - Coal properties, burner performance, and overall plant performance
  - > 4 years, >200 parameters, >390 million datapoints

- **Neural Network Training**
  - Burner performance, heat transfer (SSH) performance, plant performance (heat rate)
  - Demonstrated impacts of fuel quality on predictions

- **Combustion System Performance Indices Algorithm Development and Testing**
  - Upgraded version of Combustion System Performance Indices (CSPI) installed at plant
  - CoalTracker used to predict adverse fuel events
  - Operator training completed: operators use CSPI daily to manage fuel properties
  - Estimated cost savings of >$6 million in 2020
CoalTracker Algorithms
Development and Testing
Full Stream Elemental Analyzer (FSEA) Installation

July 2018

Before Installation – Coal analysis results from one composite sample representing 7000 – 12000 tons of coal available after 3 days of firing.

FSEA Impact – Coal properties are reported every minute for every 90-120 tons of as-delivered fuel before firing. Flexibility of coal blending and storage.

Coal Properties from FSEA – Ash, Moisture, Heating Value, S, C, and inorganic constituents based on prompt gamma neutron activation, microwave, and dual gamma attenuation.
Coal from the mine → Belt 1/FSEA → Live Storage → Transfer Tower → Belt 7/10 → Silos → Cyclones/Boiler

- Collect and analyze coal samples
  - Continued characterization of FSEA performance
  - Obtain detailed data for CoalTracker
- Track power plant performance during the field test
- Use CSPI-CT beta version to predict plant performance
- Validate plant performance with real-time data

Total Number of Coal Samples Collected during the field test -> 149
CoalTracker Output
# CSPI-CT Plant Performance Parameter Database Development

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Data Analysis and Statistical Analysis
Ash Deposition
Forced outages - Diagnosing problems

Shutdown

As-Fired Coal Properties

On-line Predictions

- Primary Superheater Outlet Temperature v. Time
- Coal Tracker Predicted Ash Content v. Time
- Coal Tracker Predicted Na Content v. Time

Increasing Ash
High Fouling

Shutdown 1
Shutdown 2

Fouling Events Observed

Superheater Fouling Index (S-CQI)

Date
Aug 2019
Sep 2019
Oct 2019
Nov 2019
Neural Network Development Overview

- Neuro-Evolution for Time Series Data Prediction
- Methods (see next slide):
  - NEAT-based (EXALT, EXAMM)
  - Ant Colony-based (ASNE, ANTS, CANTS)
  - Transfer learning (N-ASTL)
- Operating Parameters:
  - Main Flame Intensity at 12 cyclone burners
  - Steam outlet temperature, SSH
  - Net Plant Heat Rate

- Results:
  - EXAMM vs. Traditional RNNs
  - Deep Recurrent Connections
  - Further out predictions (past the next time step)
  - Coal Tracker Integration
  - Time Shifting Coal Tracker Parameters
  - Transfer Learning
  - Production RNN Generation
  - Time-lagged Correlation Visualization
Improving Prediction with Shifted Parameters

- Microbeam’s coal tracker’s program can predict the fuel properties up to 8 hours in the future.
- When we train the binaries, we can use those fuel properties ahead of time to improve the training and testing accuracy.
- Fuel properties parameters: Base_Acid_Ratio Ash_Content Na_Content Fe_Content BTU Ash_Flow Na_Flow Fe_Flow.
- Time offset: 120 mins
Improving Predictions with Smaller Input Sub-file Size

- Input sub-files with different size (25, 50, 100 datapoints per file) are tested on EXAMM
- RNNs update the weights of the models with gradients calculated from errors obtained from smaller batches of data
- Sub-file size = 50 performs the best
Neural Network Training and Testing

*Net Plant Heat Rate and Flame Intensity*

**Net Plant Heat Rate**

**Flame Intensity**
Neural Network Training and Testing

Secondary Superheater Outlet Steam Temp
Combustion System Performance Indices (CSPI) Program Upgradation
CSPI-CT

**Coal Composition**
- Target Coal Composition - Min FSE A: Delivered Coal Properties
  - Moisture
  - Heating Value
  - Sulfur
  - Ash Composition
- Coal Quality Index
  - Ash Content
  - Base to Acid Ratio
  - Sodium Content
- Power plant Performance Index
  - Coal Quality Index
  - Over-fired Air
  - Operations Data

**Coal Handling**
- Coal Tracking Optimization
- Cyclone Performance
  - Cyclone Slagging
  - Flame Stability
- Fireside Performance
  - Wall Slagging
  - Deposits
  - HT Fouling
  - Li Fouling
  - Deposit Strength

**Cyclones**
- Silo Coal Composition
  - B/A
  - Ash
  - Sodium
- Operating Parameters
  - Load, air and coal flows
  - Air temperature
- Cyclone Performance
  - Cyclone Slagging
  - Oil burn
  - Flame stability
- Partitioning
  - Slag composition
  - Fly ash composition

**Boiler**
- Condition-based monitoring
  - Load
  - Heat rate
  - Nox temperature
  - Convective pass pressure drop
- Feedback
  - Optimum fuel properties
  - Suggestions - Target coal compositions
As-Received Fuel Properties

Coal Mining/Processing

- Coal – stock piles of varying qualities
- Full Stream Coal Analysis – Moisture, HV, S, ash composition
- Coal Tracking
- Bunkers/pulverizer/crusher
- Properties of coal delivered to each burner - coal flow
- Coal/ash Properties Database (10,000 samples)

Coal Blending Criteria

- COQI: 21.4
- SCQI: 67.6
- FSEA
- Coal Handling
- Cyclones
- Boiler
- MGA
- REE
- Diagnostics

Delivered to Live Storage

Soot blowing cycle
- Temperature, Heat flux

System design/geometry and boiler operating parameters, air flow, temperature

CSPI-CT Tools

Inputs/processes

Coal/ash Properties Database

Coal Blending Criteria

Neural Network – Training and learning for selected predictions

Manage impacts of coal properties and boiler operations

Sensors

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Boiler Operations – Cyclone and High Temperature Fouling

- Coal Mining/Processing
- Full Stream Coal Analysis – Moisture, HV, S, ash composition
- Coal Tracker
- Bunkers/pulverizer/crusher
- Coal – stock piles of varying qualities
- Properties of coal delivered to each burner – coal flow
- Ash Generator – Ash formation and partitioning during combustion
- Entrained Ash (gas, liquid, or solid)
- Transport to convective pass surfaces – Temperature, burner tilt
- Wall Slagging
- System design/geometry and boiler operating parameters, air flow, temperature
- Soot blowing cycle – Temperature, Heat flux
- Soot blowing cycle – Temperature, Heat flux
- High temperature fouling – silicate based Erosion/corrosion
- Low temperature fouling – sulfate based
- Particulate and acid gas removal
- Wall Slagging
- Transport to water wall
- Temperature, Heat flux
- Slag flow/cyclone applications
- Bottom ash or slag
- CSPI-CT Tools
- Inputs/processes – Coal/ash Properties Database (10,000 samples)
- Coal Blending Criteria – Neural Network – Training and learning for selected predictions
- Manage impacts of coal properties and boiler operations
- Sensors
- Soot blowing cycle – Temperature, Heat flux
- Soot blowing cycle – Temperature, Heat flux
- Soot blowing cycle – Temperature, Heat flux
- Historical
- Projected based on coal in silo
- B/A for optimum slag flow
- Moderate Fouling – Secondary SH
- Selected operating parameter
CSPI-CT Boiler Diagnostics
Opportunities for Plant Improvement and Cost Savings

- Installation of FSEA
  - Decreased cost of analysis
  - Opportunity to blend coal
  - Opportunity to optimize plant operating conditions to match coal properties
- Improved heat rate – coal property impacts
- Decrease oil firing through optimizing fuel properties
  - No significant oil burn event since installation and use of the technology
- Decrease fireside ash deposition - reduce number of scheduled and forced outages (maintenance costs)
- Preliminary cost savings estimated*

*All cost saving results are estimations and subject to certain assumptions. In particular, it is difficult to determine causes of derates without more detailed documentation from the plant itself, and all revenue data is an estimation based on hourly pricing and MW output without factoring in unplanned shutdowns due to tube leaks, pump failures etc.
Condition Based Monitoring (CBM) Project
Progress Summary

- Implemented 4 Novel Algorithms (EXALT, EXAMM, EXONA, CANTS)
- Trained 42 million RNNs
- NN Flame Intensity predictions
- Predicting 8 hours in the future – Net Plant Heat Rate

- 25 Databases - 23429 hours of operational data
- Life of Mine Database - 16,000 data points
- As-delivered fuel properties database – 3,000,000 data points
- As-fired fuel properties database - 500 coal short prox results
- Conducted a field test – collected 149 coal samples
- Conducted over 30 project meetings and spent over 1200 hours analyzing data
- Published 9 papers and 1 book chapter
- Currently working on updating indices with modified correlations
- Installed CSPI-CT full-featured version on-site
- Developed CoalTracker model to track fuel
- Developed phenomenological, statistical and neural network based predictive algorithms
- Developed Graphical User Interface (GUI) for CSPI-CT
Next Steps

- **Validation Field Test**
  - Planned for May 2021
  - Field test report due on May 31, 2021

- **Combustion System Performance Indices Algorithm Development and Testing**
  - Conduct neural network training for additional boiler parameters
  - Improve indices predictions based on field test data
  - Augment indices with neural network derived relationships
  - Installation and testing of a neural network based CSPI-CT

- **Operator and Plant Personnel Training**
  - Follow-up training (initial training Dec. 2020)
Questions

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