GE Energy

Slagging Mitigation Executive Summary

Hayden Station

March 2008

1. Problem Definition

Hayden Station is a coal-fired, steam-electric generating station with two operating units. The plant has three owners, with operational responsibilities held by Xcel Energy. Total plant capacity is 446 megawatts (MW); Unit 1, operational since 1965 is 184 MW and Unit 2 operational since 1976 is 262 MW. The fuel source for this plant is coal trucked from Peabody Coal's Seneca mine. Both units at Hayden Station have three different emissions control systems, including bag-houses, dry scrubbing systems and low-NOx burners. The plant is also one of the cleanest coal-fired generating stations in the region with advanced emissions control equipment. Hayden Station discharges no water offsite.

This paper explains XCEL Hayden's success in deploying the latest in automated, knowledge-based process optimization technology to reduce NOx emissions, simultaneously improving the energy efficiency of their boiler on Unit 1.

As coal is burned in a power plant, it can produce hard mineral products called slag. These combustion by-products decrease efficiency, requiring more coal to generate the same amount of electricity and resulting in increased emissions. Slagging and the associated fouling also can lead to several million dollars of lost revenue or added costs throughout a company's fleet of coal plants due to decreased load, the use of more coal and periodic plant shutdowns needed to clear out the waste.

Hayden Unit 1 uses TwentyMile coal, which has caused excessive slagging and higher NOx emissions in the past. A formal test burn was completed in 2005 to determine what modifications would be required to successfully fire this coal. The test burn showed a significant slagging problem in the high temperature superheat section. Additional boiler O2 instrumentation, a controllable primary air system, coal line flow monitors, and boiler cameras were placed in-service in 2006 which reduced slagging and NOx to within limits and allowed firing TwentyMile coal. However, slagging remained an issue, causing unit derates, unit outages and higher costs due to excessive sootblowing.

Modifying the controls to better balance the furnace proved more difficult than expected, as burner adjustments were not always logical and varied over time. A "smarter" control system was needed to improve and maintain the combustion balance.

Xcel Energy worked with GE Energy's optimization and control group to develop a first-of-its-kind software platform, which was developed to alleviate the problem. Xcel Energy began testing the system in July 2007 at Hayden Unit 1.

2. Goals

Overall project goals included:

- Reducing the hours of reduced load operation due to slagging and fouling.
- Reducing the number of forced outages for slag removal.
- Reducing 30 day NOx rolling average to 0.36 lb/MMBtu with a maximum three hour rolling NOx average of 0.43 lb/MMBtu.
- Balancing the mitigation of slagging/fouling with reduced emissions (specifically NOx) within operating constraints.
- Developing a generic improved slagging and fouling control system that can be implemented fleet wide.

3. Solution Concept

General Electric (GE) proposed a neural network software platform (called Kn3*), combined with new sensors and configured using domain experts, which provide accurate recommendations designed to optimize boiler operation in order to reduce slagging and improve efficiency and reliability. Although this innovative technology has been applied for NOx emissions, this is the first use of this technology for controlling the difficult issue of slagging.

Kn3 is the backbone of the system, capable of acquiring, managing, and displaying data, developing models that accurately predict boiler performance, and providing optimal settings for control set-points to improve performance. The system utilizes existing boiler sensors and communicates with the existing DCS to:

- Smooth the profiles of carbon monoxide (CO) and oxygen at the inlet to the convective pass. This reduces localized high particulate loading and atmospheres that contribute to excessive slagging and fouling.
- Keep furnace exist gas temperature (FEGT) at acceptable levels with a managed profile across the inlet. This will help reduce slagging and fouling globally in the boiler.

- Reduce NOx to the minimum possible while maintaining or reducing slagging, by improved air and fuel distribution.
- Keep steam temperatures at acceptable levels and relatively close to one another.

The system integrates sensor data (new and old) and operator knowledge and experience to help optimize the boiler. By using neural technology to accurately model the complex and critical inter-relationships between parameters and incorporating historical data, the system "learns" and identify patterns in boiler operation. In addition, the system has the ability to implement the "hard-won" knowledge of the plant engineers and operators via mathematical and logic rules. This was captured through data gathering interviews between plant personnel and GE experts. Combined with in-situ measurements, this approach to slagging mitigation is unique and powerful.

The software platform recommends specific combinations by using algorithms to determine the strongest family of set points to reduce emissions, balance CO and meet the FEGT target. Plant operators can adjust goals in real time to match differing conditions. The recommended set points are constrained such that no safety, operational, or environmental conditions will be violated. The software platform provides an easy-to-use interface that displays its results and allows the user to view and analyze historical data. The system is a client-server design in nature, accessible through the plant computer network and integrated with the distributed control system (DCS).

The following parameters were recommended as control setpoints for optimization:

- Excess oxygen
- Burner secondary air damper positions
- Mill biases

4. Design Components

GE's scope of work included:

- Supplying a proprietary software platform to provide recommendations for boiler operations to reduce slagging and fouling.
- Providing and installing hardware and third-party software to support the GE software platform.
- Deploying the software platform with the CO / O2 grid sensor information and other plant-specific operating parameters.

Xcel Energy's scope of work included:

- Making all required connections to the DCS network and software.
- Providing technical and operational support and maintenance and instrumental repairs.

5. Results

5.1 Slagging

During the test period the neural network significantly decreased slagging:

- Lost generation events decreased from an average of 0.9 per month over 18 months, to zero over the test period.
- The slag that did occur visibly changed for the better and was easier to remove. Sootblowing and associated maintenance costs were substantially reduced. No boiler hydroblasting (water lance removal) was required, although pre-neural network history suggests an average 8 cleaning events per year are expected.

The benefit of the reduced slagging is estimated at $272,100 annually. The impact on slagging was quantified by comparing the frequency of daily sootblowing runs from the baseline period to the test period *(Figure 1)*.

During the baseline, an average of 82 blows a day occurred showing slagging was an issue. Also of interest is that 28% of the period these blowers were operated over 100 blows/day. This indicates that slagging was a problem quite often and the slag was hard to remove as it took many blows to clean it up.

During July and August, the operators were fairly engaged and followed the recommendations as the neural network worked the majority of the time and they could see positive improvements in boiler operation. The data shows there was a significant 56% reduction in sootblowing to 34 blows/day over this period and exceeding 100 blow/day occurred only 1.6% of the period verses 28% of the baseline period. Slagging was significantly reduced.

During September and October, the neural network was down quite often and thus was not used much by the operators to make adjustments. During this period, sootblowing decreased 35% from the baseline period; however, sootblowing, and thus slagging, increased compared to the previous two months when operators were following neural network recommendations. While this was not a planned part of the testing, it demonstrates that some of the adjustments made were likely permanent, while others require neural network recommendations to maintain the reduced slagging.

In early November, the NOx model was implemented along with a modified O2 balance model. The O2 balance was modified to improve the quality of the recommendations and neural network availability. To reduce NOx, excess air to the unit must be lowered, which past experience has shown increases slagging issues. Operating at low excess air requires a well balanced furnace. Sootblowing increased to 53 blows/day from the initial implementation of 34 blows/day, which was still a 36% improvement from the baseline period when the unit operated at higher O2. Bad days, defined as blowing more than 100 times, were only 1.9% of the period verses 28% of the baseline. Some increase in blowing would be expected due to operating at lower O2.

Overall, the data clearly shows that sootblowing in the superheat area and thus slagging issues decreased with the neural network in operation. The unit was able to operate without slagging issues at a lower O2 than has been historically possible on the TwentyMile coal. There was no lost generation related to slagging during the test period and no boiler cleanings were required.

5.2 NOx Emissions Reductions

During the test period:

- The neural network helped operations decrease NOx emissions by 7% to a 30-day rolling average of 0.406 lb/MMBtu. This was less than expected and did not meet the initial project goal of a 30-day rolling average of 0.36 lb/MMBtu.
- The primary reason for the lower than expected NOx reduction is that excess air did not decrease as significantly as planned. NOx deviation at similar O2 is higher than desired and likely occurs because other uncontrolled boiler operating variables or fuel variation has a greater affect on NOx than expected.

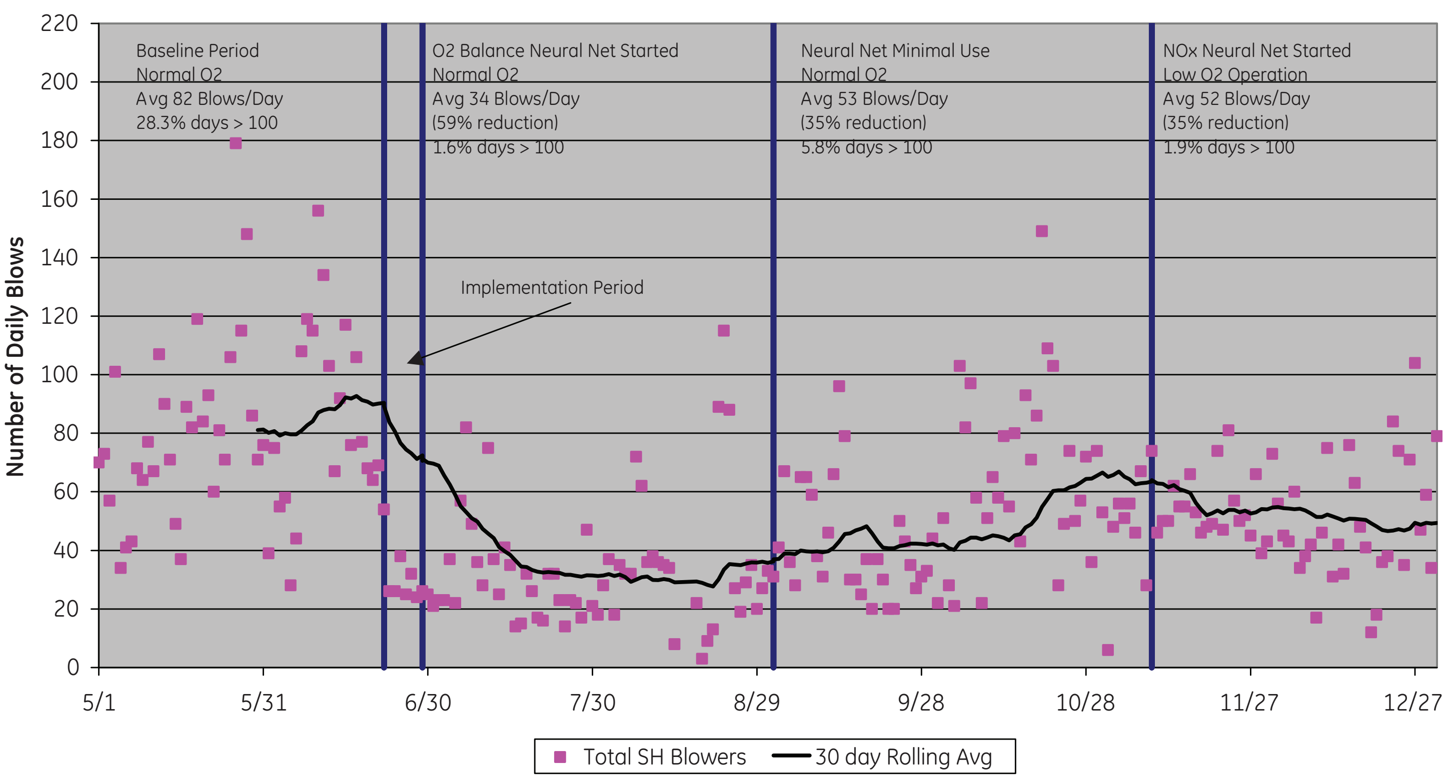

Figure 1. Hayden Superheat Sootblowing History-2007 – Left & Right Blowers 3,4,5, & 6 - 8 Blowers

- While the NOx reduction goal was not met, NOx was reduced 7% from the baseline of 0.435 lb/MMBtu during the final plant test period *(Figure 2.)* This figure shows all good hourly NOx emission data shown by periods. The data contains all loads and the NOx data below about 0.37 lb/MMBtu is generally at significantly reduced loads.

After the second GE site visit in mid September, network reliability was low and operations did not make many neural network changes in this period. Even though the network was not used in this period, there was not a significant increase in NOx during this period. This suggests that the NOx reduction was most likely a function of the combustion tuning originally completed rather than the adjustments recommended by the neural network model. Even after the NOx model was implemented, NOx reductions were very small. In early January, operators were informed that obtaining NOx below 0.39 may be required in the future and that NOx model recommendations should be made as long as they could be done without risk. There does appear to be a minor step reduction in NOx in this period and the January average decreased to 0.394 lb/MMBtu.

The basic premise of the neural network was to balance O2 to improve combustion and then reduce O2 to decrease NOx. A more complete data review to determine the reasons for the lower than expected NOx reduction revealed that there was not a decrease in excess air.

Possible reasons for this are:

- Improved boiler balancing caused an apparent reduction in the normal plant O2 instrumentation, but the actual excess air didn't significantly change during the test program.
- Increased airflow deviation due to fuel flow change from manual to auto in mid October.

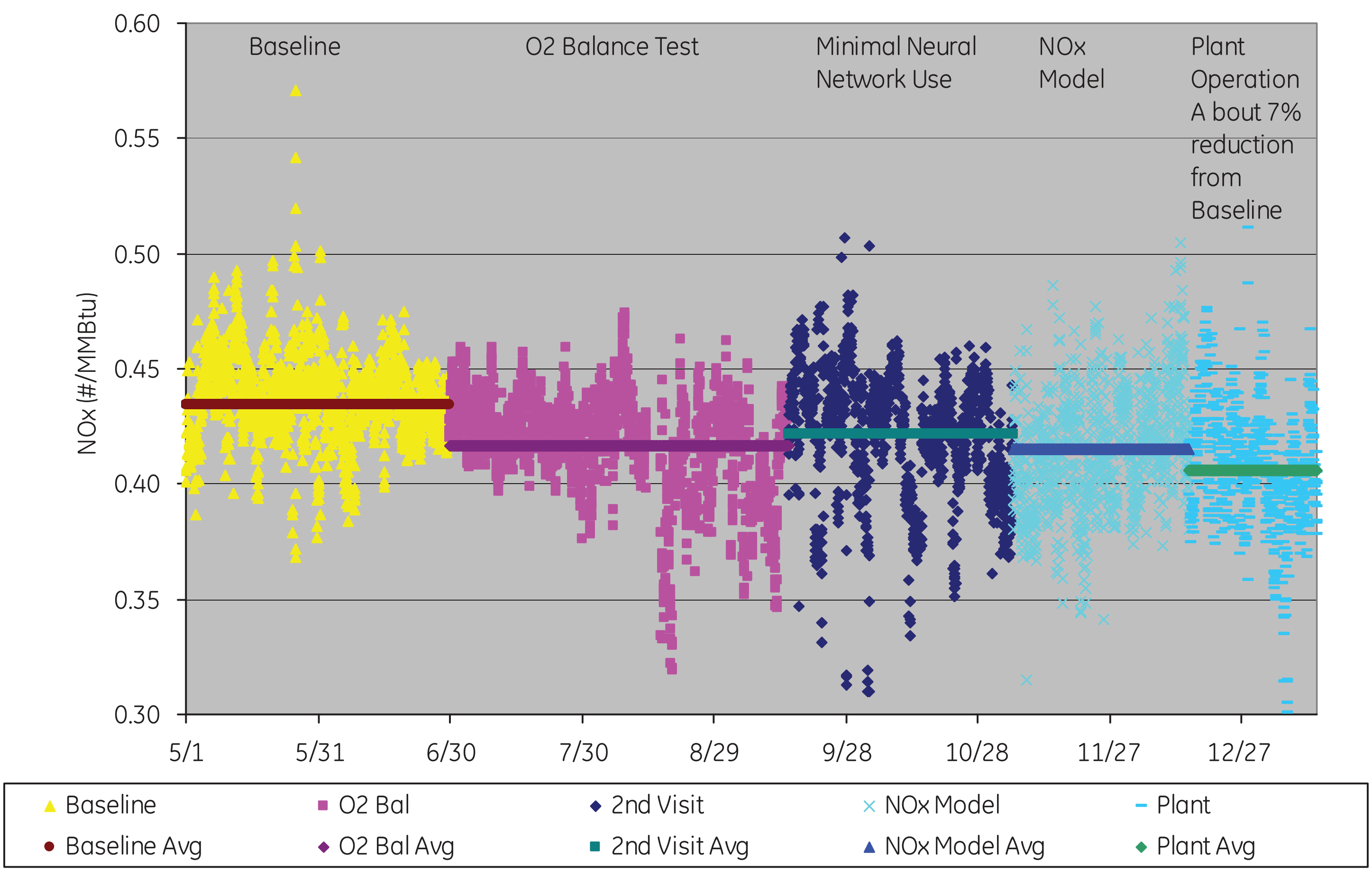

Figure 2. Hayden 1 Hourly NOx Emissions – All Good Data (no data substitution)

- O_2 reduction is limited by the difficulty of maintaining sufficient air at the sidewalls of the boiler.
- High O_2 to NOx deviation indicates that variables other than O_2 have a large effect on NOx.

It is believed that with more model work and investigation, NOx could be further reduced.

5.3 Efficiency

A minor efficiency improvement of 0.069% occurred due to reduced sootblowing and a carbon monoxide (CO) decrease of 145ppm. The reduction relates to an annual fuel savings of $15,900. There was no improvement in unburned carbon in ash. Hayden has not had a historical problem with steam temperatures and there was not a major change in boiler heat transfer with the neural network.

5.4 Overall

- The project team discovered that the key was to balance the O_2 and CO grid to a preferred profile. Stable, longterm maintenance of this balance resulted in mitigation of previous historical "hot spots" and reducing atmosphere (low O_2) regions that drove slagging and fouling. This had a dramatic, sustained effect on slagging and fouling conditions.
- The test program showed that it takes continuous adjustments to maintain the grid balance due to unit dynamic changes that occur on a daily basis.
- The team conducted operator interviews and parametric testing of the unit to identify the key elements and the cause/effect relationships that drove slagging/fouling. The software model was developed around these combustion parametric studies. The neural based software platform was "learning" as the combustion team conducted their parametric tests. When the combustion team departed, the software continued to make recommendations and provided ongoing advisory that allowed the operators to maintain optimized conditions over the long term.

6. Benefit Analysis

This effort allowed Xcel Energy to:

- Eliminate unit derates due to slagging and fouling (eight in the previous 12 months)
- Eliminate unit outages and boiler cleaning due to slagging/fouling during the test period
- Reduce sootblower maintenance and related costs by 50%
- Create minor reductions of NOx
- Reduce CO by 145 ppm
- Increase unit efficiency
- Reduce the overall "carbon footprint" of Hayden Unit 1

Over a five-year evaluation period the:

- Net Present value is $256,895
- Benefit/Cost Ratio is 1.30
- Internal Rate of Return is 53.49%
- Return on Investment is 29.88%

7. Sustainability

- Minor efficiency improvements resulted in a net heat rate improvement of 0.069%, which would be expected to decrease CO_2 emissions by 1160 tons.
- Future improvements in the system could further improve the realized NOx reduction by 7%.

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