NOx & Heat Rate Supervisory Control at NRG-Huntley Operations

Glenn Lange, Project Manager, NRG-Huntley

Donald Labbe, Principal Engineer, Invensys

Rama Mahajanam, Application Engineer, Invensys

Tom Litchko, Application Engineer, Invensys

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Abstract

To meet the objective of lowering NO_x emissions while improving unit heat rate for Unit 67 at NRG – Huntley, a model predictive multivariable NO_x and Heat Rate Supervisory Control System was installed. This complex coal fired unit has twin furnaces with independent burner tilts and a full low NO_x burner system with separated over-fire air. The multivariable control system coordinates 15 different control variables to minimize NO_x formation while attaining the best thermal performance from the boiler. This system applies dynamic models of the process derived from brief testing to provide stable and responsive control. Since a common stack is used for both Units 67 and 68, "soft sensors" for estimating the NO_x emissions from each unit have also been integrated into the model predictive system. These sensors provide feedback to the multivariable control system emissions performance. A few simple screens provide the operator with a straightforward means to activate and monitor the Supervisory Control System. The system significantly lowered NO_x emissions while improving heat rate.

Objective

This paper describes the implementation a Supervisory Control System based on model predictive control (MPC) and an smart automatic soot blow system applied to NRG-Huntley Units 67 and 68 and presents a summary of the results.

The objectives of these systems were to reduce NO_x emissions while maintaining or improving unit heat rate. These systems were installed on Unit 67 in the summer of 2001, passing a performance test in early September. Subsequently, the systems were commissioned on Unit 68 in December 2001 and January 2002.

The challenge of the project was to improve performance beyond that achieved by the implementation of low NO_x burners, separated over-fire air and a fully tuned regulatory control system.

Approach

NO_x emissions are influenced by the air and fuel distribution in the furnace. Similarly, the thermal performance of the boiler and turbine are also influenced by these same parameters. A supervisory control system was installed applying model predictive control (Ref. 1). The supervisory control system coordinates 15 different control variables to minimize NO_x formation while addressing thermal performance from the boiler. The supervisory control system uses models of the process derived from brief testing conducted earlier in the project to provide stable and responsive control.

The smart automatic soot blow system works in conjunction with the multivariable control system to assist in improving thermal performance. Fouling of the boiler caused by soot deposits adversely impacts the distribution of energy to the boiler sections. Although the surface area of the boiler sections cannot be varied dynamically, the cleanliness of the sections can be controlled by soot blowing. The system controls the distribution of energy by cleaning boiler sections based on thermal criteria and not only improves thermal performance, but also contributes to the reduction of NO_x emissions.

Basic Principles of Supervisory Control

The supervisory control system applies a dynamic multivariable controller in conjunction with an optimizer. The multivariable controller (MVC) provides fast response to maintain the process near setpoints and within constraints. Since a multivariable controller can often satisfy the control objectives with multiple solutions, the optimizer drives the controlled variables (CV) to the most profitable operating point. The optimizer provides direction to the multivariable controller by assigning setpoints to controlled variables that have a range of acceptable values and by gently pushing the manipulated variables (MV) towards their most profitable operating point. The effects of Feedforward variables (FV) are also included as models in the controller.

Model predictive control provides the following advantages over conventional control:

- Better constraint control, since the controller has the ability to “look into the future” to predict future constraint violations and thus take preemptive action.
- Time based models that handle long process lag times, dead times and inverse response.
- The ability to take multivariable interactions into account
- The ability to determine an optimal set of moves that minimizes a cost function and maximizes profit (Ref. 2 & 3).

The **Optimizer** runs at the same control interval as the model predictive controller and updates the set of long range optimum operating points for each of the controlled and manipulated variables. It provides:

- Optimum setpoints for controlled variables
- Targets for the manipulated variables that gradually move these towards optimum

The following figure shows the relation between the model predictive controller, the optimizer and the DCS.

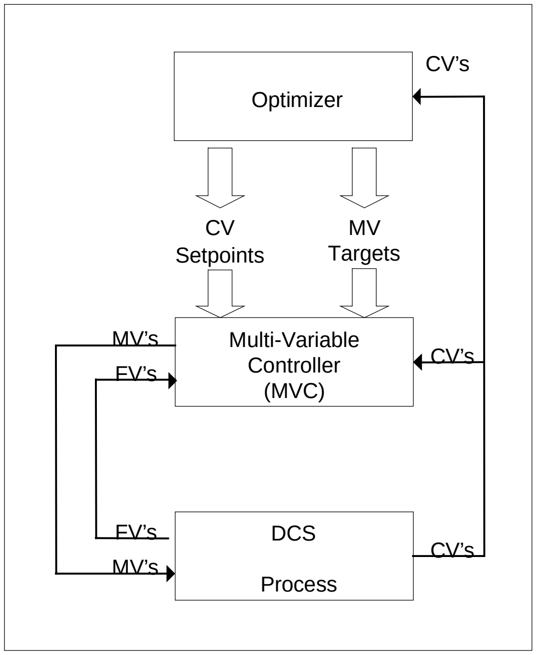

FIG. 1 – CONTROLLER OVERVIEW

The MVC/optimizer approach provides the means to satisfy the dual objectives of rapid response to transient variations, such as load following or placing a mill in/out of service and most efficient performance by gradually driving towards the most profitable operating point.

Soft Sensors for NO_x

A common stack is used for both Units 67 and 68 with a single stack monitoring system. To determine the relative contributions of NO_x emissions for Units 67 and 68, "soft sensors" for estimating the NO_x emissions from each unit were integrated into the supervisory system. In addition, since each unit has two furnaces, NO_x soft sensors were implemented for each furnace. These sensors provide feedback to the multivariable control systems emissions performance.

Each unit's NO_x soft sensor controller is a model predictive controller that operates in "predict mode". Using field data the NO_x is predicted for a unit and each furnace. Applying the stack NO_x reading as a correction feedback, the soft sensor values for the total unit NO_x, reheat furnace NO_x and superheat furnace NO_x for both Units 67 and 68 are output. These values are cascaded as controlled variables to a master NO_x controller for each unit.

The outputs from the Master NO_x Controller are targets that are fed to the optimizer and then cascaded to the MVC controller and used by the MVC controller to control the NO_x for that specific unit. The following figure depicts the relation between all four controllers – the NO_x soft sensor controller, master NO_x controller, and the main Optimizer and MVC controller.

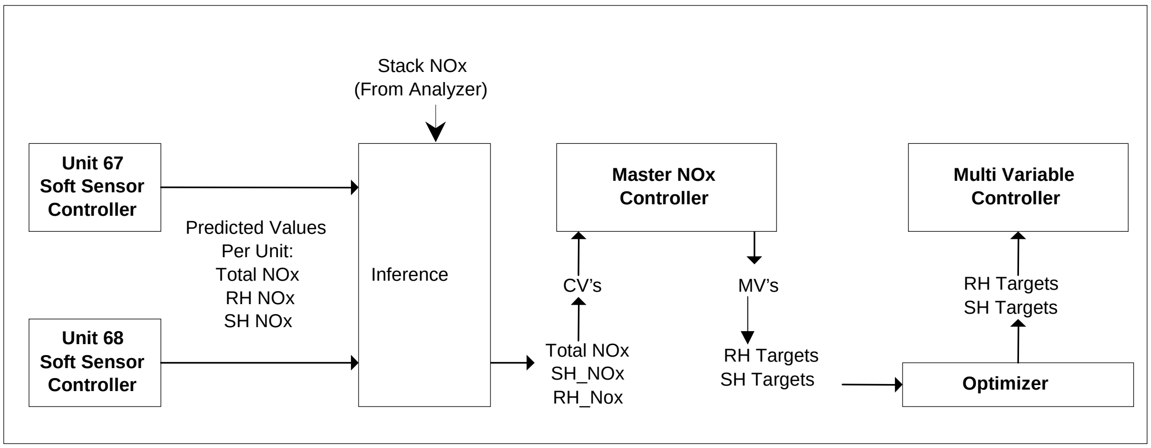

FIG. 2 – OVERALL NO_x CONTROLLER LAYOUT

The approach illustrates the flexibility of MPC. Through the application of models, MPC predicts the control action required maintaining the process near setpoint and within constraint. Also, these models can predict controlled variables, such as NO_x, and used as inputs to the final controller. The soft sensors, inference calculation, master NO_x controller, optimizer and multivariable controller were all included in the same package and executed in a coordinated mode.

Twin Furnace Variables

The twin furnace design with physically separate furnaces for the superheat and reheat functions increases the number of controlled and manipulated variables and complicates the control through the highly interactive effects.

The large number of air dampers and fuel inputs all have a significant impact on the emissions and thermal performance of the unit. While conventional single loop control can not effectively handle such highly interactive processes, multivariable control is specifically designed for such processes.

The schematic below illustrates the large number of variables and process interactions associated with the twin furnace design.

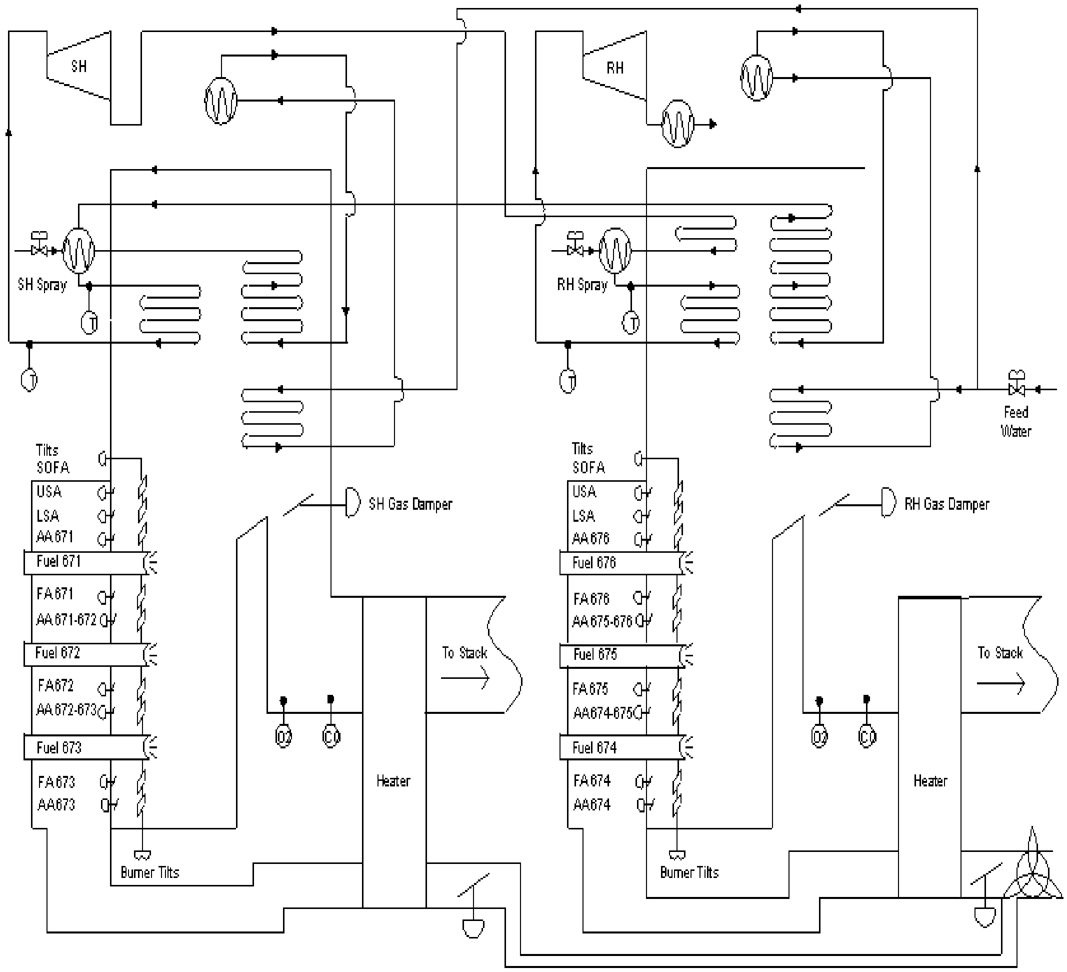

FIG. 3 – FURNACE CONTROL SCHEMATIC

The controls regulate the distribution of air and fuel between furnaces and within a furnace. Since each furnace has a specific effect on superheat or reheat steam temperatures, the furnace to furnace distribution plays a strong role in the MPC. As NO_x is strongly influenced by the fuel and air distribution within a furnace, fuel and air biasing along the furnace path are also included in the controller.

Operator Interface

While multivariable model predictive control is inherently complex in order to achieve robust and effective control, the operator interface to the system must be both simple and flexible to achieve high "up-time" and the associated benefits.

The threefold objectives of the operator display are the following:

- allow the operator to place the unit under supervisory control
- allow the operator to add/remove select loops to/from supervisory control
- provide the operator a window to observe the status of the supervisory control

The following custom display was provided for this application.

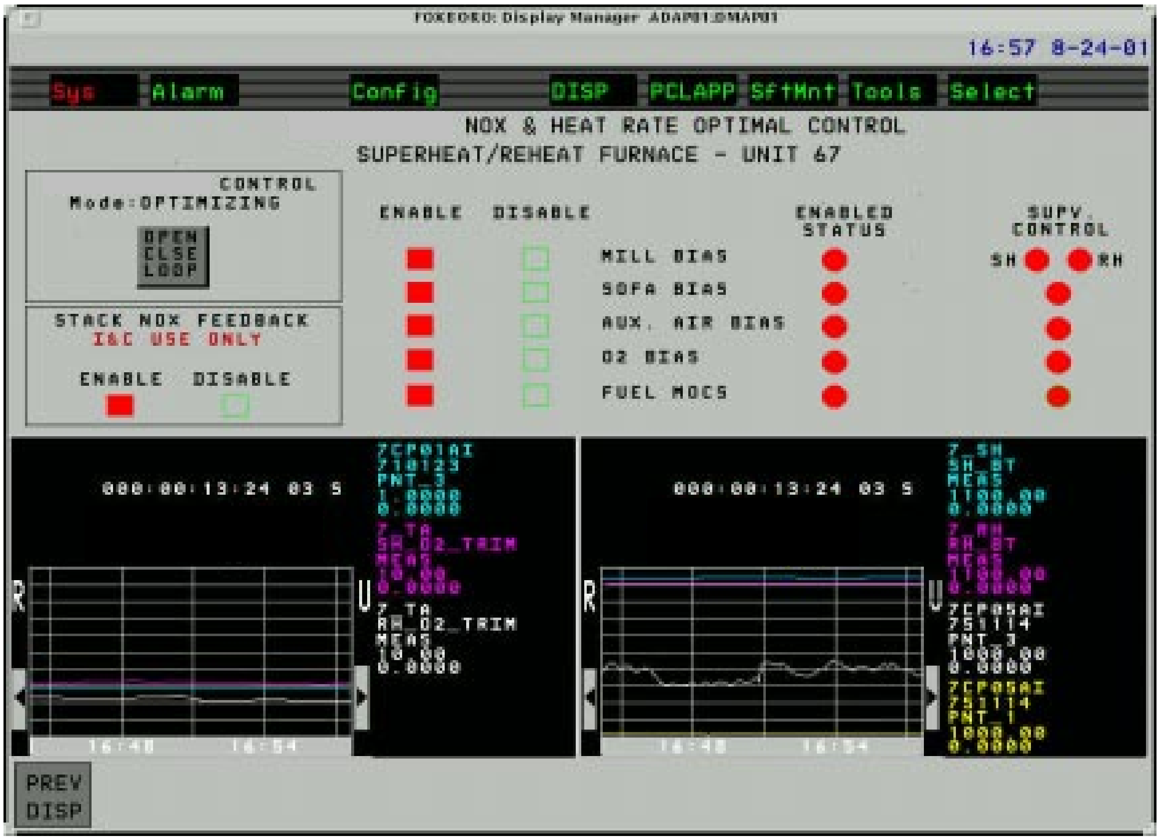

FIG. 4 OPERATOR SCREEN

Five sets of loops are available to be individually enabled or disabled. This allows the controller to be maintained "on-line" to achieve partial benefits while certain control loops may not be available. The controller can also operate without stack NO_x feedback. Since the operator has several methods to quickly override supervisory control for emergencies, such as a feeder trip, the status lights provide a quick indication of loops under supervisory control.

Additional detailed graphics provide the operator and engineer with information on each individual MV and CV in the supervisory system, such as signal control status, optimum target, current value, and last move. These displays also provide access to setpoints and high and low constraints. Additionally, certain existing graphics were modified to provide required information on the status of the supervisory signals.

Smart Automatic Soot Blow

A key component of the overall system is a smart automatic soot blow system. This system provides the means to use the furnace fouling as a dynamic heat transfer control, directing heat to the appropriate sections of the furnace. Following a shutdown, thermal performance of the unit actually improves as the boiler transitions from fully clean to selectively clean by the automatic system.

Prior to the installation of the system the operators were generally reluctant to activate many blowers due to possible adverse effects on thermal performance. For example, blowing several wall blowers at a particular load could overshoot the intended effect and drop steam temperatures well below setpoint. Typically, the operators would occasionally activate certain blowers with known effects to address major performance issues. The remaining blowers would remain inactive for long periods.

The automatic system calls on the full range of soot blowers, yet maintains the performance measures near expectations and this has supported operator acceptance. Further, by freeing the operator from the duties associated with soot blow; the operators have been very receptive to the system.

The system applies rule-based logic as an expert system. It combines multiple sensor inputs for temperatures, pressures, and other measurements to determine soot blow requirements.

The smart automatic soot blow system overlays the standard soot blower control package. The system mimics the attentive operator by selecting individual blowers in a gradual process of controlling the energy distribution in the furnace. By optimizing energy distribution, more freedom is provided to the control of NO_x and heat rate.

The primary operator display for the smart automatic soot blow system includes an on/off selection with detailed soot blower status information. Additional configuration display allows the engineer to adjust soot blower maintenance status, weighting and importance factors.

NO_x & Heat Rate Performance

The supervisory control system for Unit 67 has been operating nearly continuously since August 2001. Unit 68 has been operating with the supervisory control system since December 2001. To evaluate the performance, select tests have been conducted. The objectives were to meet aggressive NO_x emissions targets while not adversely impacting heat rate. These objectives were met or exceeded.

As an example of the performance that has been achieved, the supervisory controller was intentionally removed from service for several hours to evaluate the impact on emissions and thermal performance. The graph below illustrates the main steam temperature and the NO_x emissions. The next trend illustrates the furnace O_2 and air flow increase for the same transition.

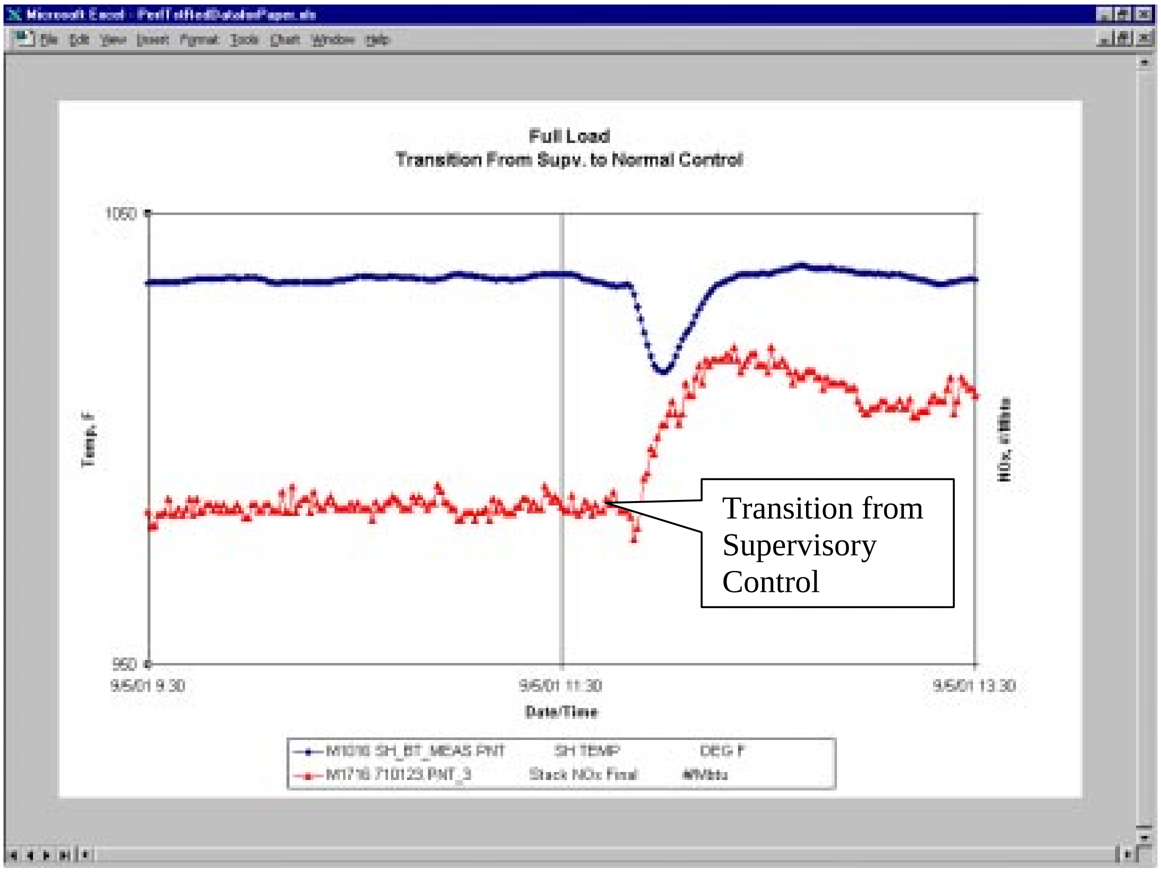

FIG. 5- NO_x FOLLOWING TRANSITION

The shedding of the Supervisory control to normal control is configured to gradually back-out the supervisory bias signals, so there are no major upsets in the air and flow controls. However, the steam temperature with its long time response, does experience an upset as the conventional control gradually responds. The NO_x emissions increase dramatically under conventional control.

Although difficult to quantify, the heat rate impact of the supervisory system is illustrated by the change in furnace O_2 and air flow. This graph shows the sharp transition in superheat and reheat furnace O_2 as well as the total air flow to the furnaces.

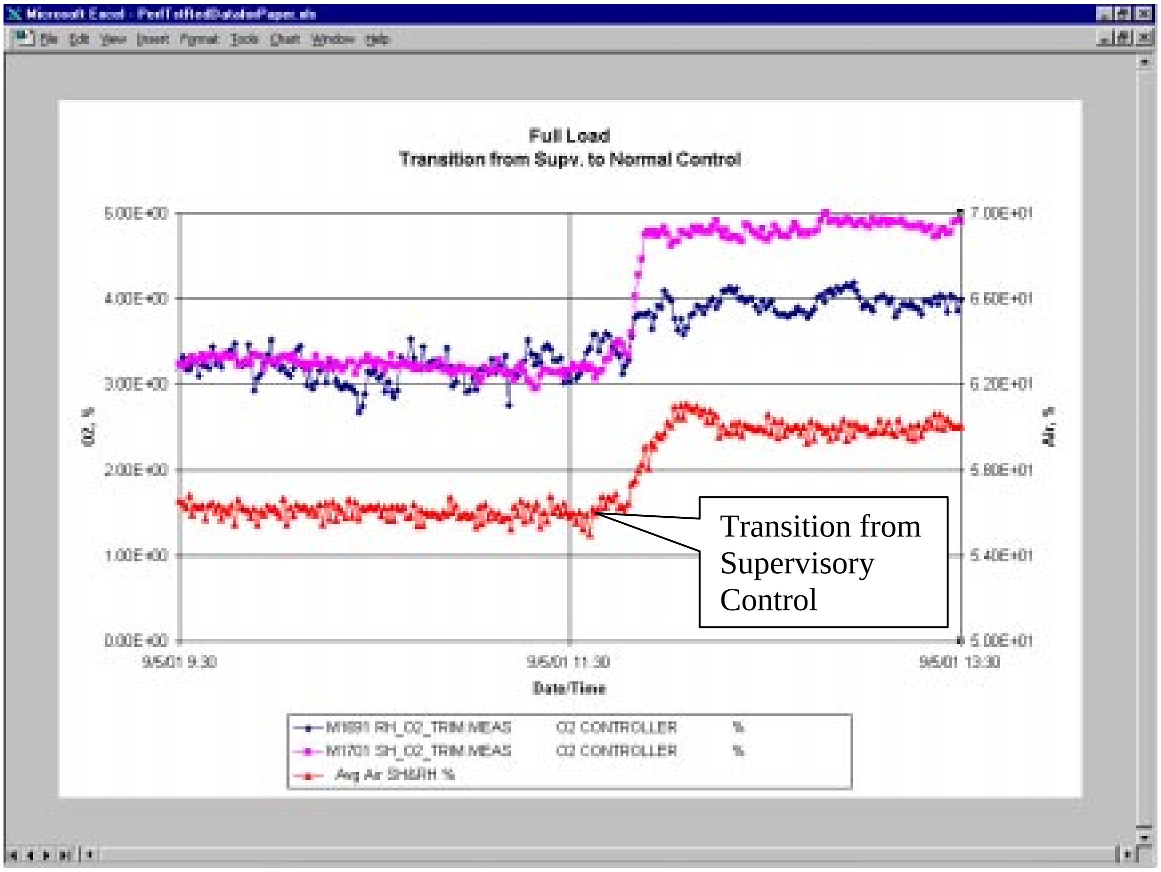

FIG. 6 - O_2 & AIR FOLLOWING TRANSITION

The average O_2 increased from 3.3% to 4.4% increasing the air flow from 56% to 60% as a result of turning the supervisory controller Off-Line. This increase in air flow corresponds to an increase in dry gas losses and is estimated to represent greater than a 0.4% increase in unit heat rate. Additional heat rate benefits are associated with the reduction in stack temperature associated with lower O_2. The calculated loss applies the dry gas loss approach for Ohio Bituminous Coal presented in reference 4.

Since the supervisory control includes dynamic components it assists in the control of certain variables, such as steam temperature. Although steam temperature is primarily controlled through the DCS by burner tilt position, the O_2 control provided by the supervisory control augments the burner tilts and reduces temperature variations during transients. Figure 7 illustrates the superheat temperature response to fast load changes near full load. Both the burner tilts and the O_2 respond to the temperature upset and quickly return the temperature to setpoint.

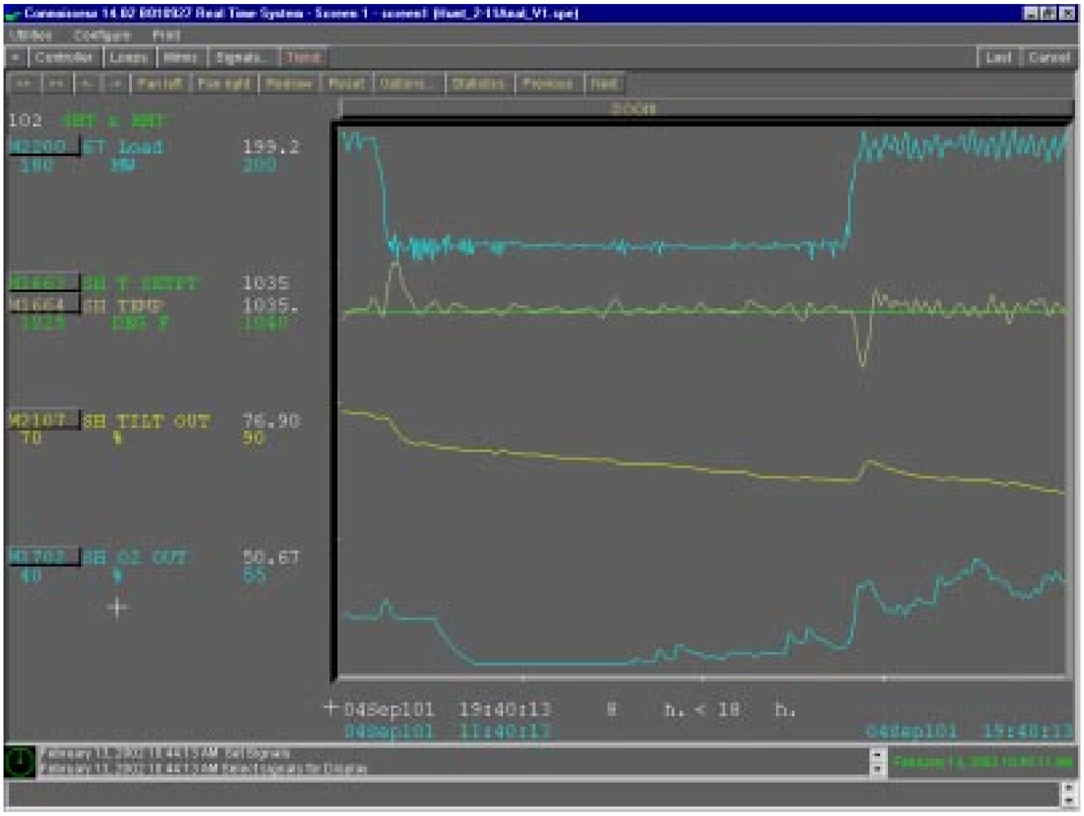

FIG. 7 – STEAM TEMP DURING LOAD CHANGES

Conclusions

The NO_x and Heat Rate Supervisory Control system combined model predictive control and a smart automatic soot blow system to satisfy the NO_x and heat rate targets for the project. The complex furnace and multi-unit design led to a large number of manipulated variables and soft sensors that were implemented through the supervisory control. The NO_x performance was improved by more than 10% over the prior condition, which included low NO_x burners, separated over-fire air and a fully tuned control system. Heat rate improvements of more than 40 Btu/KW-hr are also indicated. The operator interface has proved to be both easy and effective for operator control of the system. This has resulted in high utilization of the supervisory control system.

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