GNOCIS - Continuous Combustion Optimization for Utility Boilers

Scott Allison
Mike Slatsky
John Sorge
Southern Company

Ian Mayes
PowerGen

Bill Menzies
Radian International

Tom Brown
U. S. Department of Energy

Jeff Stallings
Electric Power Research Institute

ABSTRACT

GNOCIS (Generic NO_x Control Intelligent System) is a methodology that can result in improved boiler efficiency and reduced NO_x emissions from fossil fuel fired boilers. Using a numerical model of the combustion process, GNOCIS applies an optimizing procedure to identify the best set points for the plant on a continuous basis. The optimization occurs over a wide range of operating conditions. Once determined, the recommended setpoints can be implemented automatically without operator intervention (closed-loop), or, at the plant's discretion, conveyed to the plant operators for implementation (open-loop). GNOCIS is designed to run on a stand-alone workstation networked to the digital control system, or internally on some digital control systems. The developmental sites for GNOCIS are Alabama Power Company's Gaston Unit 4, a 270 MW wall-fired unit, and PowerGen's Kingsnorth Unit 1, a 500 MW tangentially-fired unit. This paper provides a general overview of the technology and results from testing at these two locations. In addition, GNOCIS is also being installed on other utility boilers and results will be presented from these sites as available. The development of GNOCIS was funded by a consortium consisting of the Electric Power Research Institute, PowerGen, Southern Company, Radian International, U.K. Department of Trade and Industry, and U.S. Department of Energy.

INTRODUCTION

Deregulation of the industry has forced utilities to improve operating efficiencies of their units in an effort to reduce overall operating cost and become more competitive. Also, passage of the 1990 Clean Air Act Amendments has challenged U.S. electric utilities to reduce nitrogen oxide (NO_x) emissions and to maintain these low emission rates during day-to-day operation. Boiler efficiency, fly ash carbon-in-ash (CIA or LOI), and NO_x emissions are strongly influenced by a number of controllable and uncontrollable operating parameters. Due to the combustion complexity and high coupling of a number of important process parameters associated with boiler combustion -- especially for pulverized coal fired units -- it is difficult to obtain an optimum or even acceptable operating point. When one operating parameter is improved, another is usually adversely affected. Therefore, delicate balancing is needed to maintain the optimum over a wide operating range and for extended periods. The difficulty in optimization is compounded on units with low NO_x combustion technologies installed.

GNOCIS

GNOCIS (Generic NOx Control Intelligent System) is an enhancement to digital control systems (DCS) targeted at improving utility boiler efficiency and reducing emissions. GNOCIS is designed to operate on

units burning gas, oil, or coal and is available for all combustion firing geometries. GNOCIS utilizes a neural-network model of the combustion characteristics of the boiler that reflects both short-term and longer-term trends in boiler characteristics. A constrained-nonlinear optimizing procedure is applied to identify the best set points for the plant. These recommended set points can be implemented automatically without operator intervention (closed-loop), or, at the plant's discretion, conveyed to the plant operators for implementation (open-loop). The software incorporates sensor validation techniques and is designed for continuous on-line use. The major elements of GNOCIS are shown in Figure 1.

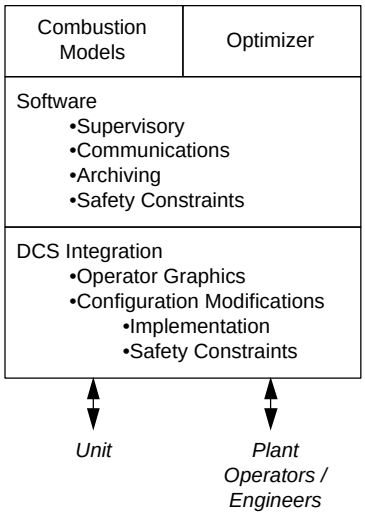

Figure 1. Major Elements of GNOCIS

Alabama Power Company's Gaston Unit 4, a 270 MW wall-fired unit, and PowerGen's Kingsnorth Unit 1, a 500 MW tangentially-fired unit served as developmental sites for GNOCIS. Demonstrations of GNOCIS are also underway at a number of other sites including Georgia Power Company's Hammond Unit 4, Entergy's Nelson Unit 4, Duquense's Cheswick Unit 1, and PowerGen's Kingsnorth Unit 3. Results from Kingsnorth Unit 1 and Gaston Unit 4 are presented in this paper.

GNOCIS development was funded by a consortium consisting of the Electric Power Research Institute, PowerGen, Southern Company, Radian International, U.K. Department of Trade and Industry, and U.S. Department of Energy.

THE GASTON TRIAL

The objective of the Gaston trial is to develop and demonstrate GNOCIS on a wall-fired unit. Gaston Unit 4 is a 270 MW pulverized coal unit. The Babcock and Wilcox (B&W) opposed-wall-fired boiler is arranged with nine burners (3W x 3H) on two opposing walls such that no burner has another burner directly across from it. Combustion air is supplied to the burners via common wind boxes on each side of the boiler. The unit is equipped with B&W XCL low NO_x burners and six B&W EL-76 ball and race mills. Fuel is delivered to the mills by two-speed table feeders. The unit has two forced-draft fans, six primary air fans, and two flue gas recirculation fans. Combustion air is heated with Ljungstrom air preheaters. The boiler control system for Gaston Unit 4 is a Leeds and Northrup Max 1000 distributed digital control system. The control system is designed such that the unit is controlled through the CRTs -- there are no bench board mounted controls.

GNOCIS Implementation

The original objective at Gaston was to implement an open-loop, advisory system with no immediate plans to migrate to closed-loop operation. This objective influenced the original design philosophy in a number of respects, primarily selection and quantity of control variables, increased demand for flexible and informative operator displays, and reduced necessity for stringent recommendation checking and incorporation of safeguards. However, during the course of the project, it was determined that there were significant benefits, both in performance and ease of use of the system, if upgrades were made to GNOCIS to enable closed-loop operation. These enhancements also give the operator an easier way to implement open-loop recommendations.

Figure 2 shows the informational flow for the GNOCIS implementation at Gaston. All process data is collected through the DCS and passed on to the GNOCIS host (a PC running WindowsNT) for calculation of the recommendations. These recommendations are then conveyed to the operator via the DCS operator displays. If acceptable, the operator can then implement these changes through the DCS operator displays. Also, the operator has the option of running GNOCIS closed-loop in which the recommendations are automatically implemented. The primary operator display, which resides on the

DCS, is shown in Figure 3.

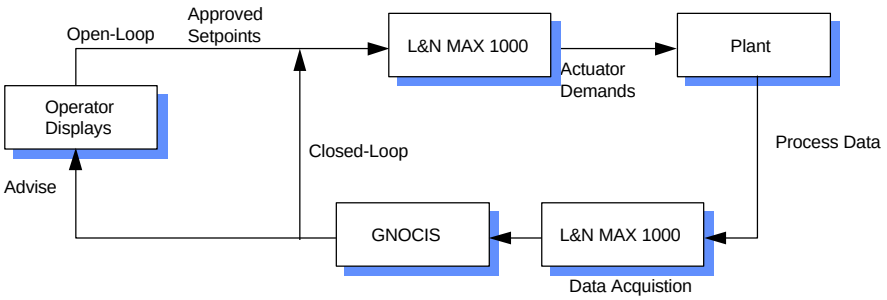

Figure 2. Gaston / GNOCIS Installation

Model Development

Data collected through the DCS was used to create the combustion models. Although in excess of 1000 points are being archived in the DCS, early in the project, a subset of approximately 100 parameters were identified as being possibly important for combustion modeling purposes. Modeling efforts have concentrated on the most recent three to four months of long-term data. Short-term tests were run periodically during which the unit was run at off-design conditions to augment data available from normal operation and thereby expand the range over which the combustion model could make estimates. Also, results from testing GNOCIS were generally included in the training data for future models. The collected data was preprocessed to remove invalid data and to some extent, data collected during transients. In general, the existing control system and instrumentation provided an excellent platform for the collection of real-time process data in a format usable by GNOCIS.

Trial Results

Preliminary open-loop testing of GNOCIS was conducted during 2nd quarter 1995. The combustion model used during these tests was based on training data collected during October and November 1994 and February 1995. Based on these tests, it was evident that the models needed to be retrained using more recent data. Although the actual reason for model inaccuracies still are unknown, possible factors include the result in ongoing mill maintenance or an undetected change in coal characteristics. In September 1995, further open-loop testing was conducted. In general, predictions and recommendations made by GNOCIS were robust and beneficial. The results of two tests are shown in Figures 4 and 5. In the first, GNOCIS was directed to maximize efficiency with no limitations placed on LOI, NO_x and CO and an approximate 0.5 percent improvement in efficiency. In the latter, the reduction of NO_x emissions was the objective with the improvement being approximately 15 percent.

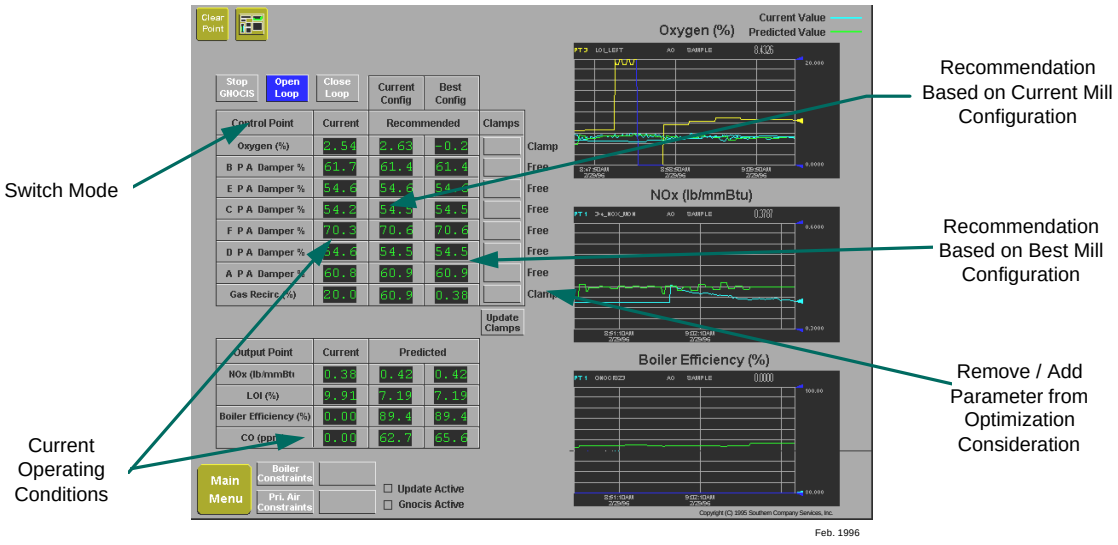

Figure 3. Gaston / GNOCIS Operator Interface

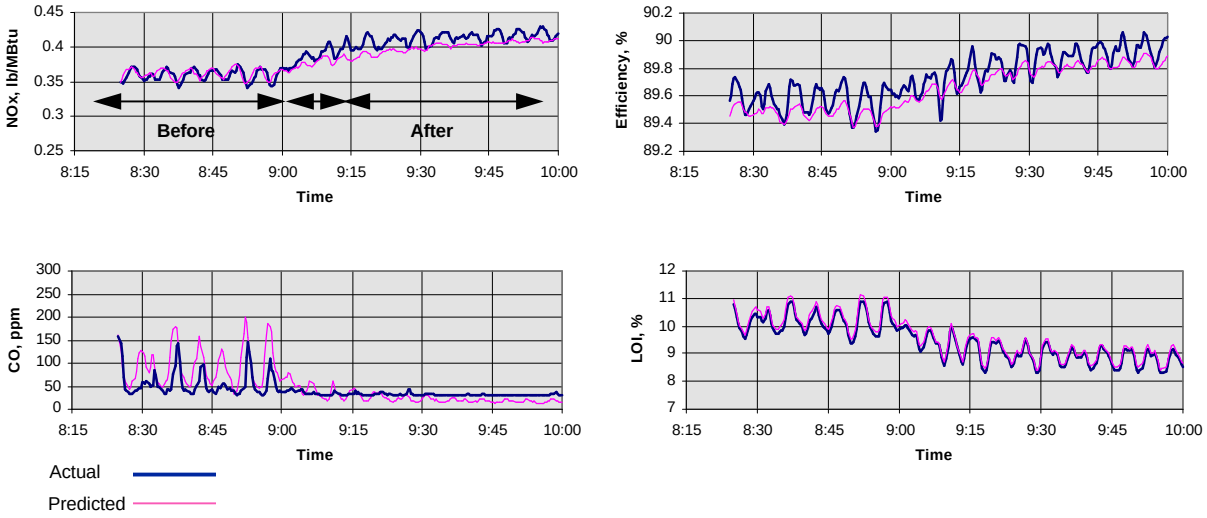

Figure 4. Gaston / Maximize Efficiency Objective

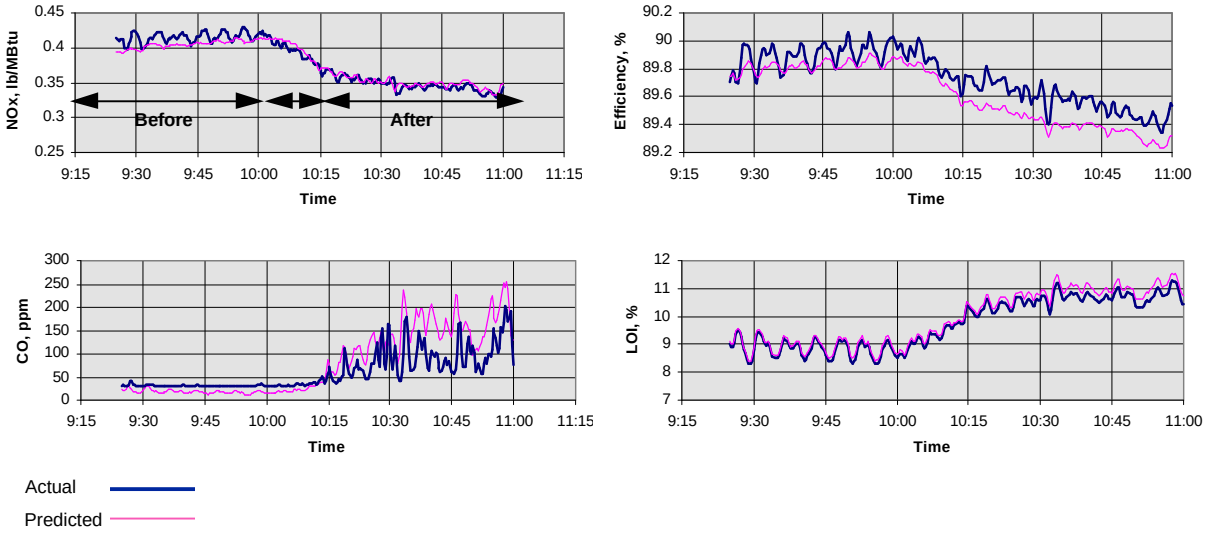

Figure 5. Gaston / Minimize NOx Objective

Since these initial tests, GNOCIS has been converted to closed-loop operation. Although testing is yet to be completed, example results are shown in Figure 6. Data shown in this figure are from when the unit is under economic dispatch and between 250 and 270 MW. Also, excess O_2 was excluded from the optimization determinations (i.e. no recommendations were made for O_2). As shown, LOI was reduced by approximately 2.5 percent and boiler efficiency improved by nearly 0.4 percent.

THE KINGSNORTH TRIAL

Kingsnorth Power Station is located near London. Unit 1 is a 500 MW tangential-fired unit equipped with a NEI International Combustion boiler and is capable of meeting full load on either pulverized coal or residual fuel oil. The furnace has a central vertical dividing wall which forms two identical combustion chambers. The four burner boxes in each chamber have independent tilt control which can be moved nominally between +20 and -20° from the horizontal. Each mill fires a single level within the furnace. The furnace is fitted with a low NO_x firing system with separated and close-coupled overfire air. The digital control system at Kingsnorth uses an in-house system known as CUTLASS which is based on DEC PDP 11 hardware and Instem I/O equipment. The primary objective at Kingsnorth is to minimize

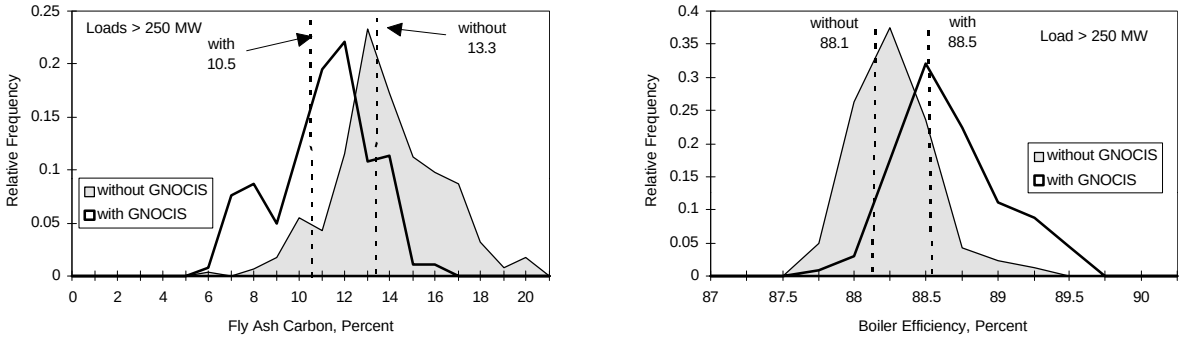

Figure 6. Gaston / Maximize Efficiency / Closed-Loop

CIA in the fly ash while maintaining NO_x below the current level of 390 ppm. With the current DCS configuration, only seven parameters are adjustable by the operators - burner tilts (ganged together as one setting), excess air, and five mill settings; therefore these parameters were selected for use in GNOCIS.

Model Development

The data acquisition system was receiving and storing data twenty-four hours a day throughout the Kingsnorth trials. However, not all data was suitable for use in the models; in its raw form the data covered periods when the instrumentation was faulty and when the plant was operating in a regime outside of the GNOCIS specification (zero and low load). Data was therefore preprocessed to remove invalid data and data not corresponding to GNOCIS operating regimes. Predictive models were constructed, as a first step, to give an indication for the overall accuracy of the modeling and to highlight potential difficulties. The performance of the model was evaluated by selecting up to four periods of operation, omitting these from the input data and then running the model on this data. Similar to the predictive model evaluation, four periods of operation were chosen against which the model performance would be assessed. This was done for the control models by taking expert advice on what information should have been given to an operator to prompt any desired control action. The experts were the Kingsnorth Efficiency Engineer and a PowerGen combustion expert. This advice was then compared with control advice suggested by the model.

Trial Results

Testing of GNOCIS at Kingsnorth began November 1994 and was completed in January 1996. During these tests, the primary interest was to evaluate the performance of GNOCIS especially in regard to its ability to produce recommendations that would result in reduced carbon-in-ash. The final tests of GNOCIS were conducted during four days of testing in December 1995 and February 1996.

In the December test, GNOCIS was set to give advice so that carbon-in-ash would be minimized and NO_x would remain below 390 ppm (the NO_x limit for the unit). During one day of trials, the advice would be taken and during the next it would be ignored and the unit run at the non-optimized, normal settings. GNOCIS recommended significant changes in A and E feeder, excess oxygen, and burner tilt. As shown in Figure 7, carbon-in-ash was reduced from 15 percent to near 11 percent with minimal impact on NO_x emissions. In the February tests, the objective was modified to minimize NO_x emissions. As shown in Figure 8, NO_x emissions were reduced by near 10 percent with little effect on carbon-in-ash.

CONCLUSIONS

A summary of the project and the results to date are as follows:

- GNOCIS has been successfully deployed at both Kingsnorth and Gaston.

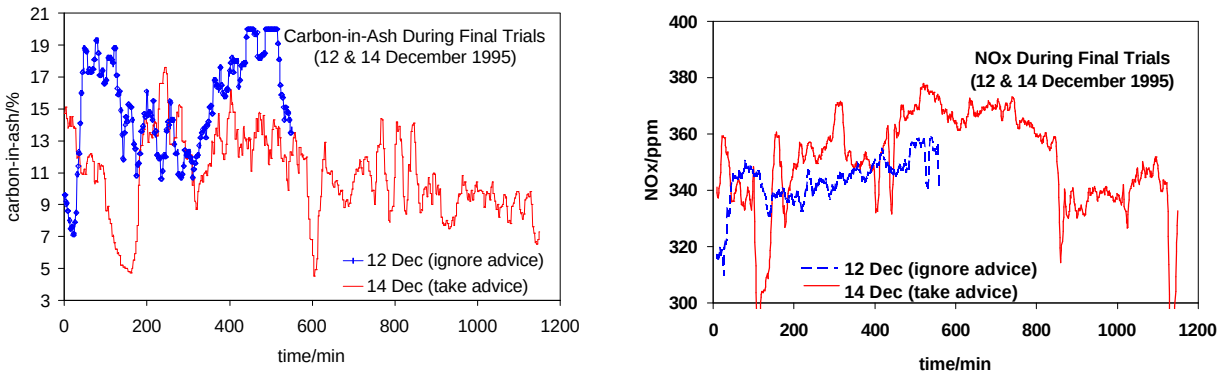

Figure 7. Kingsnorth / GNOCIS Minimize Carbon-in-Ash

- GNOCIS was able to provide advice which reduced carbon-in-ash and improved boiler efficiency significantly at both sites.
- GNOCIS provided advice which reduced NO_x emissions.
- The advice GNOCIS makes is consistent with good engineering judgment.

The original developmental and test program at Kingsnorth and Gaston is nearing completion, however, these sites will continue to be used to develop and demonstrate enhancements to GNOCIS.

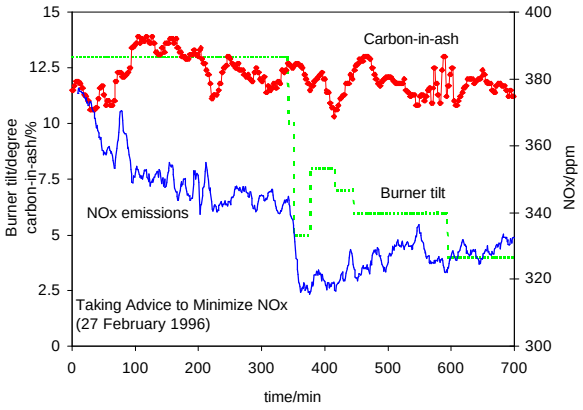

Figure 8. Kingsnorth / GNOCIS Minimize NOx

ACKNOWLEDGMENTS

The authors wish to gratefully acknowledge the following for their guidance, support, and efforts related to the GNOCIS Project: Gary Fotheringham, Rob Holmes, and Rick Squires, PowerGen; Jim Noblett and Mark Hebets, Radian International. Also, the support from Rabindra Chakraborty, ETSU, Dave Crockford, DTI and Scott Smouse, DOE is greatly appreciated. Lastly, we would like to thank the staff at both Gaston and Kingsnorth and in particular Peter Hayward (Kingsnorth) and Carzell Walton (Gaston) for their gracious toleration of our frequent requests and for allowing their units to be developmental sites for GNOCIS.

REFERENCES

1. Holmes, R., Squires, R., Sorge, J., Chakraborty, R., McIlvried, T., "Progress Report on the Development of a Generic NOx Control Intelligent System (GNOCIS)," EPRI 1994 Workshop on NOx Controls for Utility Boilers, May 11-13, 1994, Scottsdale, Arizona.

2. Holmes, R., Mayes, I., Irons, R., Sorge, J. N., Stallings, J. W., "GNOCIS An Update of the Generic NOx Control Intelligent System," EPRI/EPA 1995 Joint Symposium on Stationary NO_x Control, May 15-19, 1995, Kansas City, Missouri.

3. Fotheringham, G., Holmes, R., Mayes, I.,Squires, R. T., "GNOCIS - The Generic NO_x Control Intelligent System - Final Report", Report prepared by PowerGen, 1996.