Illinois Power's Online Dynamic Optimization of Cyclone Boilers for Efficiency And Emissions Improvement

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Abstract

Illinois Power Company (IP) is a leader in implementing online dynamic optimization at its fossil-fired power stations. As part of the company's Phase II CAAA compliance plan, IP proceeded with similar online systems at its Baldwin, Wood River, Havana, and Vermilion stations for all 10 of its coal-fired units. These Operator Advisory Systems utilize the Ultramax Method™ and Dynamic Optimization, known as ULTRAMAXÆ.

Of particular interest are the installations on Baldwin Units 1 and 2, which are 575 MW B&W cyclone units. Throughout the power generation industry, there has been great concern about how to deal with high NO_x levels and meet EPA regulations while avoiding excessive capital costs. Based on previous applications of ULTRAMAX to cyclone units, a successful control strategy was employed for optimization of the Baldwin cyclones. These empirical model structures were then integrated with Baldwin's Distributed Control System (DCS), a Westinghouse WDPF interfaced with an Oil Systems Plant Information System (PI), to provide continuous online optimization. The online optimization system meets IP's objectives of NO_x reduction and concurrent improvement in boiler efficiency. IP benefits by achieving compliance with emission regulations while securing cost savings and a rapid return on investment.

Implementing ULTRAMAX as an integrated online solution on the Baldwin cyclone boilers, as well as Unit 3, a 595 MW ABB-CE tangential unit, assists the operator when conditions change, simplifies data collection and enables daily updating of boiler models. This continuous use of an integrated dynamic solution offers the opportunity for greater emissions control, fuel savings, and the ability to respond rapidly and flexibly to changes in operating conditions, compliance regulations and the market environment.

Introduction

Illinois Power Company (IPC) is a leader in implementing online advanced boiler optimization at its fossil-fired power stations. This is an important element in IPC's strategy for compliance with Phase II of the 1990 Clean Air Act Amendments as well as achieving least-cost operation to meet the challenges of the developing competitive environment in the electric power industry. To help meet these two objectives, IPC proceeded with online continuous optimization systems for all 10 of its coal-fired units at the Baldwin, Wood River, Havana, and Vermilion stations. To achieve least-cost compliant performance, these units utilize ULTRAMAXÆ Dynamic Optimization in online advisory mode.

The decision to move ahead with advanced optimization on coal-fired units was based on the success of the initial implementation of Dynamic Optimization on Unit 2 at their Hennepin Power Station[1]. It provided IPC with firm evidence that:

1. Dynamic Optimization is an effective approach to rapidly optimizing a boiler unit to achieve multiple objectives of NO_x control and boiler efficiency.
2. The Operator Advisory System can be effectively utilized by operations personnel as a support tool for continuous improvement and response to changing conditions.

At Hennepin, the real-time advisory optimization system integrates ULTRAMAX software with the Westinghouse WDPF II DCS that controls Unit 2, a tangential, coal-fired boiler with a twin-furnace, rated at 235 MW. At full load, this advisory solution has achieved improvements in boiler efficiency of more than 3%, and NO_x of more than 20%, while constraining other emission and performance parameters to avoid adverse effects. Figure 1 shows the NO_x improvements as the software discovered better control settings. Figure 2 combines NO_x and boiler efficiency into a single measure called Goal. The greatest effects on NO_x came from lowering O_2 trim and tightening upper windbox dampers, while boiler efficiency benefited most from the same damper positions. Models of a variety of operating scenarios have been created by operators to advise best control parameter settings at all operating conditions. These models, updated daily to reflect the current status of the boiler, enable the operator to respond to changing load and fuel conditions, burners out of service, and other situations that affect boiler performance.

Implementing Dynamic Optimization Online At Baldwin Station

<u>Baldwin Boilers and Control Systems</u>

There are three boiler units at Baldwin Power Station for which Dynamic Optimization is being installed. Two are 580 MW B&W cyclone boiler units that burn coal in their 14 opposed-wall cyclones. The third is a 595 MW CE tangentially-fired unit. Each has a Westinghouse WDPF II DCS which connects to a common OSI PI System for archival storage of data. The Dynamic

Optimization software is interfaced with the PI System in order to extract process data and communicate recommended new settings to the control operator (Figure 1). The recommendations are displayed on the operator's console screen for their action.

The advisory system helps the operator respond to changing load and fuel conditions, burners out of service, mill conditions and other situations that affect performance. Examples of optimization functions that the operator can perform at the console are:

- From a set of system models (operating scenarios), select the appropriate model that reflects the equipment configuration, fuel type, goals, and current operating state of the unit.
- For the selected model, implement the most effective parameter settings to attain the desired goal (e.g., maximize efficiency and limit NO_x).
- Update the models with fresh data captured from the DCS so that they reflect the current condition of the boiler.
- Test possible operating scenarios by making "what-if" queries of the models and reviewing predicted outcomes for possible implementation.
- Define alternative equipment configurations and set goals to initiate the creation of new models.

Initial empirical models of boiler combustion are being built for all three units at normal expected operating conditions. Beginning with full load, models for all operating loads will be built as these loads come into use in normal operations. Of particular interest is the need to reduce NO_x on the cyclone units because of the usual high emission levels from this type of boiler unit. Success using Dynamic Optimization in reducing NO_x emissions from cyclone units has been achieved at other plants by biasing air to the upper cyclones to produce a staging effect. The choice of control parameters to be adjusted on Baldwin Units 1 and 2 reflects this experience with previous cyclone optimizations. Figure 2 is a diagram that shows the parameters being adjusted (controlled inputs) and the many results parameters (outputs). In addition, Load is used as an uncontrolled input which means that the operator does not decide on Load, rather that decision is made by a central dispatcher. By using Load as an uncontrolled input, the unit is optimized and models are built as a function of Load even though it varies.

Dynamic Optimization On Cyclone Units

<u>Previous Cyclone Units Optimized</u>

Prior to the installation at Baldwin, ULTRAMAX Dynamic Optimization has been used effectively on two other cyclone units. These were Kansas City Power & Light's Unit 1 at LaCygne Station and Union Electric's Unit 2 at Sioux Station[2]. In both cases the objective was to reduce NO_x as low as possible at full load while constraining heat rate and other key performance parameters.

LaCygne's Unit 1 is a B&W 700 Net MW coal-fired, cyclone boiler. The unit has 18 opposed-wall cyclones on two levels. Initial optimization using ULTRAMAX in stand-alone mode produced NO_x reductions of 30% at full load. The primary control parameters that were adjusted were the O_2 setpoint, upper and lower cyclone air biases, upper and lower cyclone fuel biases, and windbox to furnace differential bias (Figure 3). The strongest effect on reducing NO_x was caused by the lower air bias followed by the upper air bias, upper fuel bias, and O_2 setpoint. A staging effect was created between the upper and lower cyclones that proved to be effective in reducing NO_x.

Unit 2 at Sioux is a B&W supercritical cyclone boiler with flue gas recirculation, rated at 500 MW. The unit has 10 opposed-wall cyclones on two levels firing a blend of 70% Powder River Basin coal and 30% Illinois coal. Because the model structure is tailored to fit each individual unit, choice of parameters to adjust for optimization was somewhat different from LaCygne.

Control parameters that were adjusted were the O_2 setpoint, upper secondary air bias, upper and lower primary/tertiary average, lower secondary air bias, gas recirculation damper, gas tempering damper, and the windbox pressure (Figure 4).

Dealing With Variation In Coal Blends

Because Sioux Unit 2 uses a blend of Powder River Basin (PRB) and Illinois coals, it was desirable to include this factor in the models based on expected variation. While the plant targets a 70% Western/30% Illinois blend, the method used for combining coals is somewhat crude and causes variation from the target. The fuel blend cannot be adjusted nor held constant for the sole purpose of reducing NO_x. Also, while fuel blend does affect NO_x, the target blend for routine operation is fixed and determined by various operating constraints and other factors.

SO_2 was chosen as an uncontrolled input due to its correlation with the coal blend. Since the Illinois coal utilized at the Sioux Plant produces higher emissions than the PRB coal, variations in the fuel blend normally have an impact on NO_x, and the ability to optimize. Therefore, there was a need to represent this variation. Because the actual coal blend could not be accurately measured, it was decided that the SO_2 level would serve as a good substitute. Union Electric personnel had previously performed studies to establish a correlation between coal blend and SO_2. This proved to be quite useful as the percentage of PRB coal did vary from 50% to 90%.

Consistent improvement in NO_x was achieved at full load for the full range of fuel blend variations. Figure 7 shows the baseline values for NO_x at varying SO_2 levels (i.e., coal blends) and Figure 8 shows the NO_x level achieved after optimization by ULTRAMAX The average NO_x reduction was approximately 25%. All other performance and emission constraints were satisfied. The reduction was achieved mainly through biasing of secondary air between the upper and lower cyclones.

Dynamic Optimization Technology

Effective Optimization Of Utility Boilers

ULTRAMAX' Dynamic Optimization is advanced empirical optimization software combined with a set of problem solution procedures that has proven effective in optimizing more than 80 boilers in the past three years, as well as hundreds of production processes. It builds on existing boiler system knowledge, models the process, and identifies control parameter adjustments to achieve improved levels of performance while staying within predetermined operations constraints. It is utilized during normal operations and can be applied to boiler systems of virtually any manufacture, type, and size, and burning any kind of fuel.

Three Modes: Closed-Loop, Advisory, Stand-Alone

Dynamic Optimization is applied in three modes of operation; online advisory, online closed-loop, and stand-alone. In online advisory mode, the software is connected electronically to the boiler's Distributed Control System (DCS), or other control system, to enable automatic collection of data and presentation of advisory information for the boiler operator. The operator reviews any recommended adjustments to control settings displayed on the console, and can override them if appropriate, before these adjustments are downloaded into the control system, by a single mouse-click or by other means.

In online closed-loop mode, the electronic connections are similar but the operator is bypassed and adjustments to control settings are made automatically. Dynamic Optimization software is interfaced with a DCS to automatically collect data and adjust settings of key control parameters, bypassing the process operator as an intermediary and decision-maker. A period of operating in advisory mode usually precedes closed-loop operating mode, and even then the operator retains the option of selecting the appropriate mode under which to operate.

In stand-alone mode, a capability unique to ULTRAMAX Dynamic Optimization, no electronic connections to the control system are necessary, with data entry and recommended adjustments usually performed manually. The software can begin advising parameter adjustments with no initial data except current operating settings and the consequent results. As it advises new settings and results are reported back, improvements are soon observed as the software learns combinations that point the direction to optimal operation. Stand-alone mode is an effective way of assuring the validity of the model structure and performing initial optimization as a proof of value before integration with a DCS. Often the stand-alone mode is used on plant processes without automatic controls or as a preliminary to online installation. Each of the three modes of implementing Dynamic Optimization has its place along the evolutionary path of process improvement as solutions grow in effectiveness and technical sophistication.

Dynamic Updating Of Boiler Combustion Models

With ULTRAMAX Dynamic Optimization, model updating, or "learning" is a never-ending process. Online, it learns with each new set of data that is collected and passed to the data base. Its models are updated to reflect the most recent conditions of the boiler each time that new data is collected from the DCS and passed to the software. These updates occur daily, even hourly, whether directed by an operator when in advisory mode, or automatically when in closed-loop mode. The cause-and-effect relationships captured in the software's empirical models allow immediate, intelligent response to changes in uncontrolled variables, such as load, fuel quality, and seasonal temperature.

Two Distinct Functions: Optimization And Modeling

A common misperception about optimization is that by developing accurate models from historical data, the optimum will be contained within the range of that model. However that is seldom true when dealing with complex processes. To discover improvements and move toward a region of optimal performance, a method must extrapolate to settings beyond the range of the historical data used to create the model. An effective solution must include both functions, optimization and modeling as represented in Figure 5. In this diagram, for the result being measured, lower is better as with heat rate, NO_x particulates or LOI.

Optimization Advantages Of Bayesian Methods

ULTRAMAX Dynamic Optimization does not depend on historical data but instead directs the collection of data for model building that is rich with information. It begins to search for better control settings as well as begin model-building with the first set of data presented to it. Bayesian analysis and internal heuristics give its models the following special characteristics when compared with other empirical modeling methods such as neural networks:

- They require no historical data to begin the optimization process. The models are built as optimization progresses eliminating a tedious "model training" period.

- They provide guidance as to which direction to search for improvements even with very sparse data. User supplied temporary boundaries limit software recommendations for early adjustments to low-risk operating ranges.
- They extrapolate very well beginning with the first set of data and progressing to optimal adjustments. This is a unique capability of the Bayesian approach which enables "intelligent decisions" based on very little data.
- The models are dynamic, not static, and no special expertise or retraining procedures are required to maintain and improve them. They adapt well to slow dynamic changes in process behavior due to unknown causes. They are refreshed and rebuilt automatically within minutes as new data are input to them, usually a daily operations procedure, so that the models always reflect the present condition of the boiler.
- They avoid fitting "noise" rather than the underlying process behavior. While excess noise, i.e., unexplained variation, is always a concern, the Bayesian models are much less sensitive to this weakness of neural network models.
- Process models are built by the operators as a particular burner configuration or fuel change is encountered. No outside "experts" are needed and no special testing situations need to be established Plant staff are self-reliant in making changes to objectives and constraints that are immediately incorporated into the models.

Software menus allow models to be examined, parameter relationships displayed in two-dimensional and three-dimensional graphs, alternative approaches tested, and various analyses performed to enable engineers to learn the behavior and limits of their existing equipment. Optimization is a never-ending activity which combines equipment modifications and a deep understanding of how to extract the most from it.

Conclusion

Illinois Power has enjoyed excellent success with ULTRAMAX Dynamic Optimization beginning with its Hennepin Station and proceeding with Baldwin Station that includes two cyclone boilers. Early optimization results on the Baldwin Station ULTRAMAX Dynamic Optimization beginning with its Hennepin units are very promising. Similar online installations are in progress at Wood River and Havana Stations. Each plant will have the capability of operating at highest boiler efficiency levels at all loads, and at the same time meeting their emission compliance requirements. Each unit can be operated with consistency shift to shift, operator to operator. With online Dynamic Optimization implemented on each of its fossil-fired boiler units, IPC will be in an excellent position to meet the competitive challenges of a deregulated electric industry, as well as to respond to changing emission compliance requirements. Not only will they be able to address the changing NO_x compliance levels, but they will be positioned to respond to the particulate and mercury limits that are expected.

References

1. Krueger, M.S., and Patterson, P.D., "Illinois Power's Online Operator Advisory System To Control NOx and Improve Boiler Efficiency: An Update." Paper presented at the *American Power Conference*, Chicago, IL, 1997.
2. Stuckmeyer, K., and Boyle, R.L., "Optimization of Cyclone Boiler for NOx Control." Paper presented at *EPRI Workshop/NOx Controls for Utility Boilers*, Cincinnati, OH, 1996.

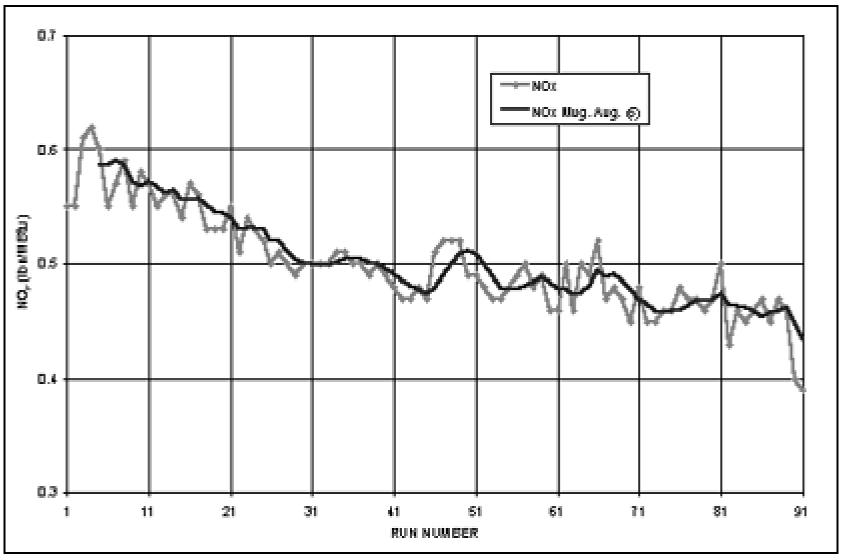

Figure 1 - NO_x Progress Chart (run-by-run)

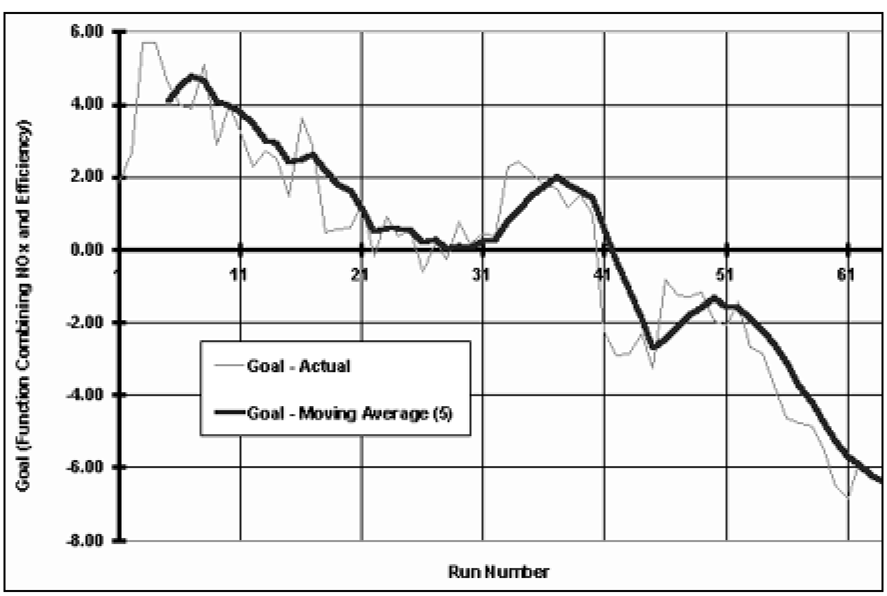

Figure 2 - Goal Progress (run-by-run)

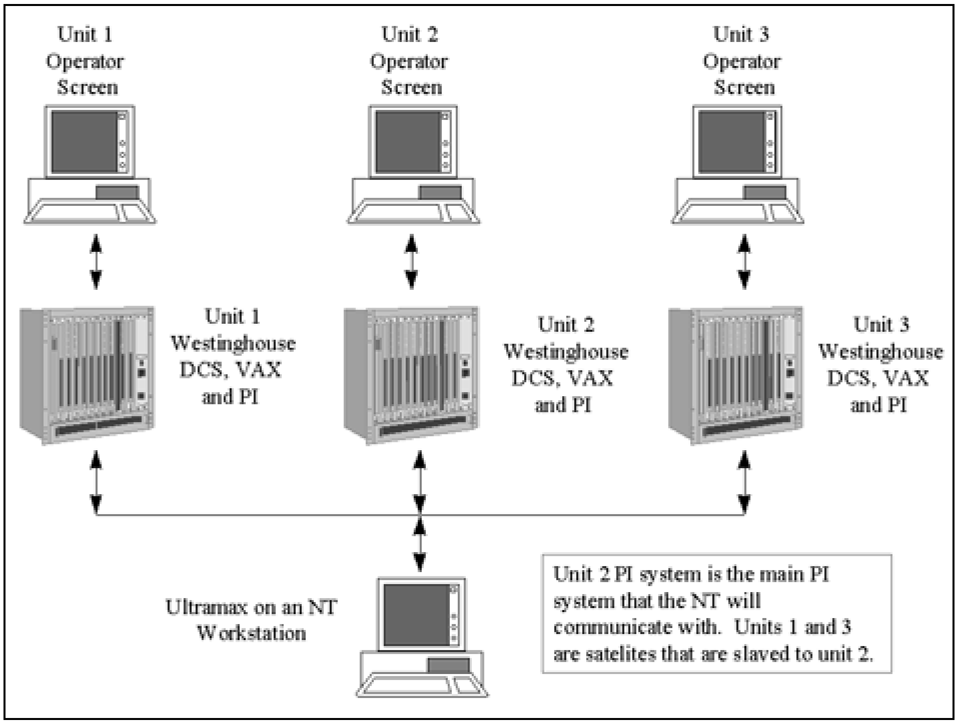

Figure 3 - Control Diagram For Baldwin Online System

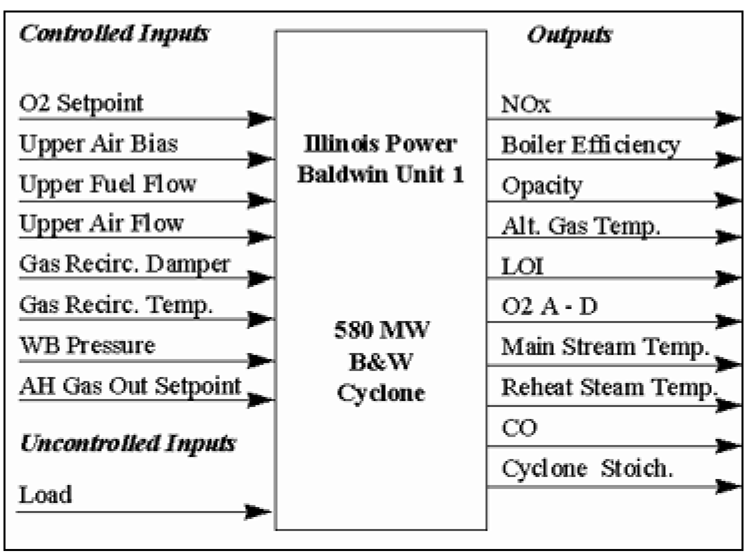

Figure 4 - Model Structure for Baldwin Unit 1 Cyclone

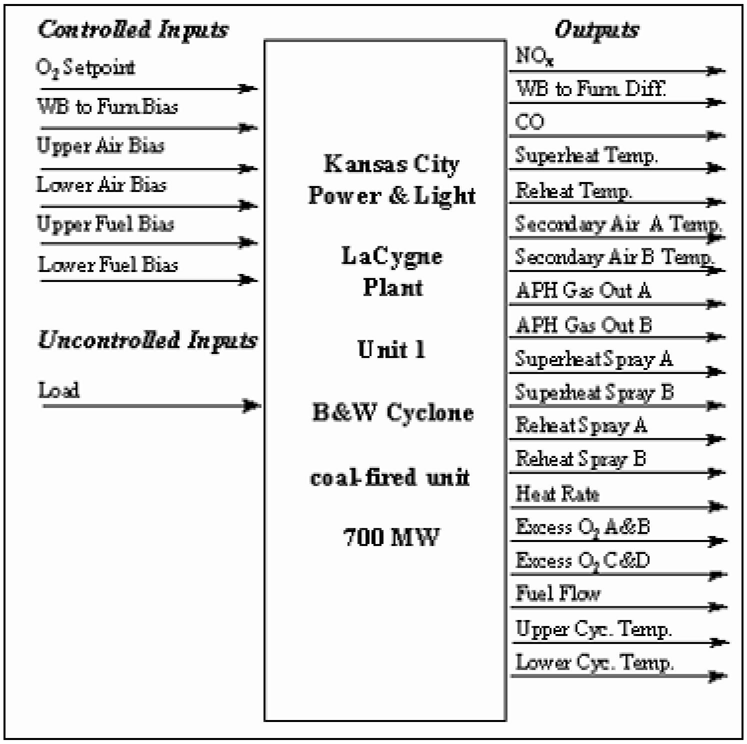

Figure 5 - Model Structure for LaCygne Unit 1 Cyclone

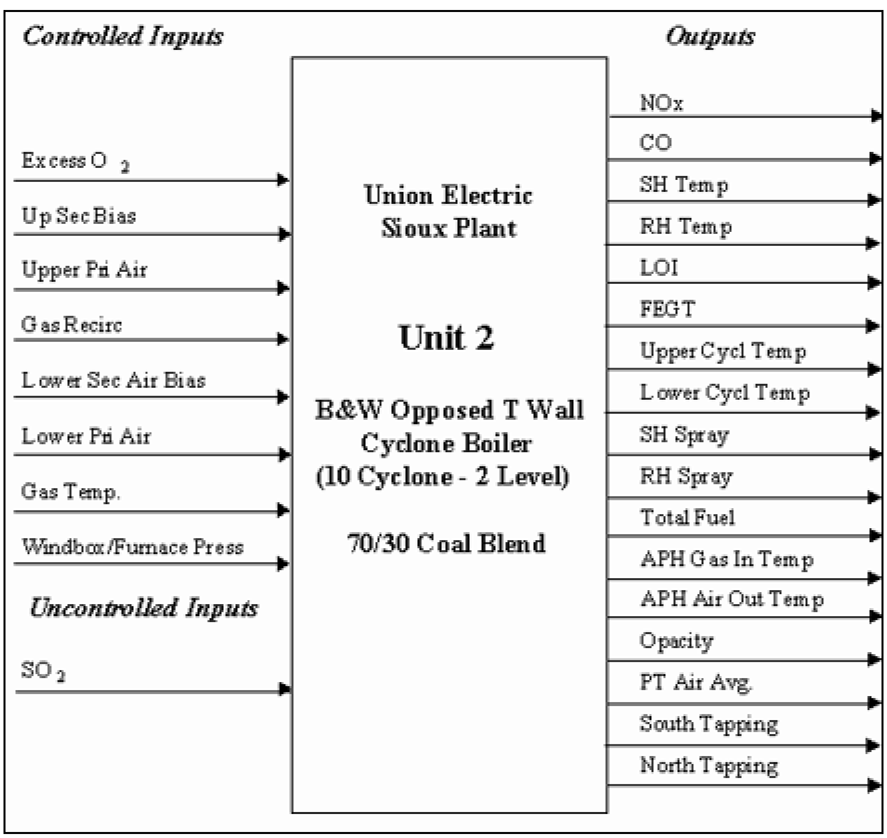

Figure 6 - Model Structure for Sioux Unit 2 Cyclone

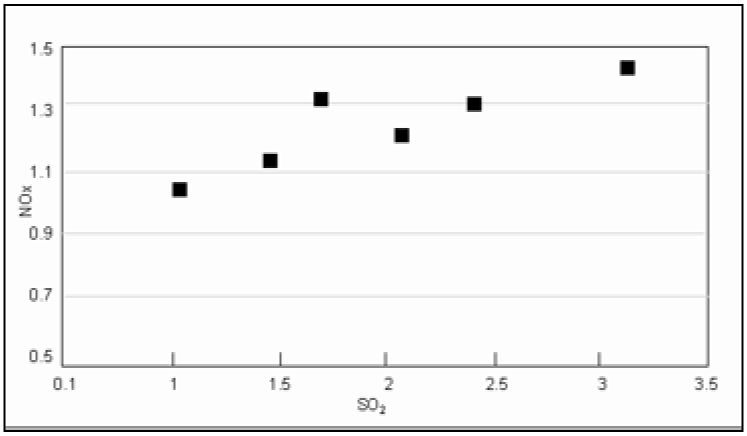

Figure 7 - NOx vs. SO2 - Baseline, Sioux Unit 2

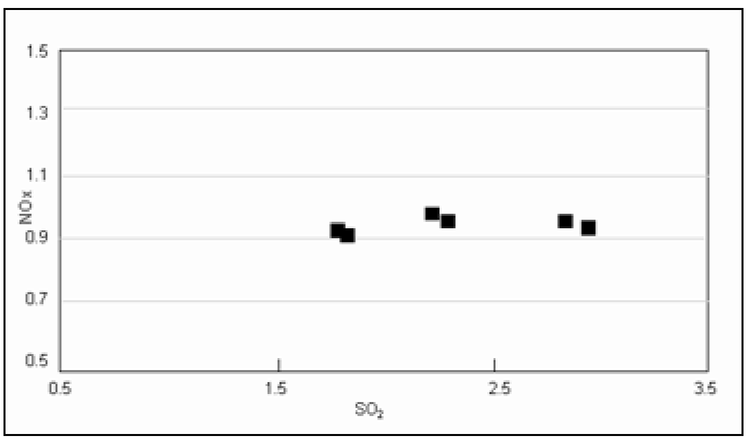

Figure 8 - NOx vs. SO2 - ULTRAMAX Optimized, Sioux Unit 2

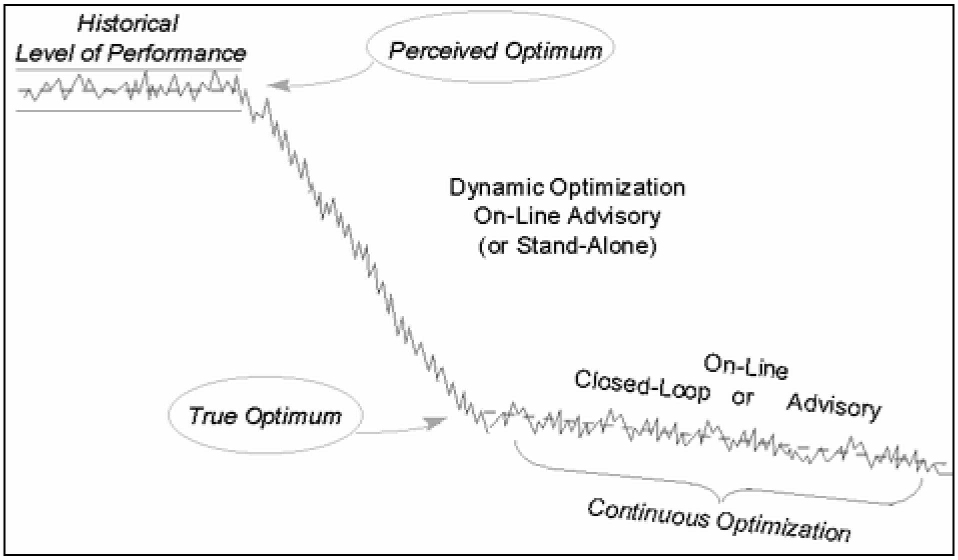

Figure 9 - The Path to True Optimization