NRG Big Cajun II: Changing Times, Continuous Optimization

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I. INTRODUCTION

The Big Cajun II coal-fired power plant is owned and operated by NRG Energy, and is located outside of Baton Rouge, Louisiana. Big Cajun II's culture embraces innovation, and the plant is open to implementing emerging technologies that can improve operational and financial performance. The plant was one of the earliest adopters of NeuCo's combustion optimization system, which has resulted in improved heat rate, lowered NOx, enhanced utilization of NOx hardware retrofits, and better overall operational performance.

Big Cajun II's optimization initiative has evolved and expanded over the past eight years:

Stage 1: Combustion Optimization on Two Units

- Installing CombustionOpt® on Units 1 & 2

Stage 2: Combustion Optimization Expansion

- Adding manipulated variables available via the addition of new NOx control hardware installed at Units 1 and 2; and
- Installing CombustionOpt at Big Cajun II Unit 3.

Stage 3: Real-Time Performance Management & Combustion Optimization Upgrades

- Adding a real-time performance management system on Unit 1; and
- Upgrading the CombustionOpt systems at all three units.

This paper describes the benefits achieved and lessons learned over the eight years the combustion optimization systems have been operating at this plant. It also describes the way in which the technology accommodated new operating requirements and associated changes in unit equipment, as well as how the success at this plant paved the way for broader use of the technology at NRG assets in the Northeast, the Mid-Atlantic, and California. Finally, it describes Big Cajun II's recent initiative to upgrade CombustionOpt to the most recent version and to add NeuCo's PerformanceOpt® system in order to increase the heat rate improvements already achieved and to improve combustion performance.

II. STAGE 1: COMBUSTION OPTIMIZATION ON TWO UNITS

Big Cajun II Units 1 and 2 were selected for the initial installation of CombustionOpt. These units, which began commercial operation in 1981, are 575 MW Riley Turbo boilers. Both units burn Powder River Basin (PRB) low-sulfur coal. Each unit is equipped with 32 opposed burners fed by four Riley ball-tube mill pulverizers. Both units are controlled with a Foxboro I/A DCS. These units operate in a mixture of base load and intermediate modes, with a historical capacity factor of approximately 60%.

Like most power plants today, Cajun's revenue and profitability depend directly on the ability to sell power on the wholesale electricity market, itself a function of the costs of production for each unit. Since the value of Cajun's generating assets is strongly affected by competitive position, management has placed a great deal of emphasis in recent years on efforts to improve (reduce) heat rate.

Big Cajun II engineering personnel and its OEM boiler supplier Babcock Power (then DB Riley) had also observed a high degree of variability in excess O_2 levels as measured by the oxygen probes across the back of the furnace. Efforts to balance fuel and air distribution had not been successful in reducing this variability. Despite the potential benefits, operators were not traditionally willing to reduce air-to-fuel ratios due to concerns about CO and the other symptoms associated with oxygen-deficient combustion.

Objectives

It was clear to plant personnel that more efficient combustion could only be achieved by considering all of the variables affecting the mixture and distribution of fuel and air within the firebox and also flue gas in the superheater and reheat sections of the furnace. The principles of combustion also suggested that the conditions leading to improved efficiency – better fuel-air distribution, reduced excess air, and lower variability – would also result in reduced nitrogen oxide (NOx) emissions. Thus the ability to obtain simultaneous heat rate and NOx reductions through CombustionOpt was an additional motivation for adopting the technology.

Methodology

Big Cajun II had been working with Babcock Power in prior years to improve operating performance using traditional methods of combustion improvement. Having addressed the major hardware issues, process control optimization was the next logical step in improving performance and NeuCo's CombustionOpt system was selected.

The Big Cajun project team also decided on two additional enhancements: carbon monoxide (CO) monitors and a data historian. While CombustionOpt included predictive CO models, used primarily as a constraint during optimization, direct feedback from the newly-installed CO monitors was used to ensure safe operations at reduced levels of excess air.

The key objectives for the project included improvements to CO and NOx in the flue gas, firebox oxygen, and boiler efficiency. To achieve that, models were developed for Boiler Efficiency (BE), NOx, CO, O_2 (at four locations), and Gross Output (MW).

CombustionOpt's models were retrained daily, combining results from the previous day with a rolling window of historical training data. This ensured that the models remained accurate, even as the plant's response drifted over time. Key variables that were optimized by CombustionOpt for the initial installations on Units 1 and 2 included:

Variables	**# of Inputs**
O_2 Bias	1
FD Fan Bias	1
ID Fan Bias	1
Furnace Pressure	1
Aux Air Bias	4
Classifier Exit Temperature	4
Fuel Flow Bias	4
Mill Power	4
Mill Feeder Speed Bias	4

Operators could select the objective functions (e.g., maximum efficiency or reduced emissions), and could also choose which operating parameters to adjust.

O_2 Control. CombustionOpt improves unit operations by reducing the control variability of key parameters. At Big Cajun II, the data generated by the various design of experiments (adjustments) of key variables were used in CombustionOpt to continually

increase the consistency and accuracy of its models, which allowed tighter control through minimizing variance.

For instance, CombustionOpt was able to identify the variability of O_2 measurements caused by the Reheat and Superheat (SH/RH) Proportional Dampers. Since these inaccurate measurements were being used to drive the control system, extra leeway had to be provided in the operating region to account for the variability. As a result of this measurement error, the O_2 setpoint was set to the center of this region; consequently, the average boiler efficiency was penalized.

The system was also able to use additional information, such as damper biases and O_2/CO measurements, to control the process in the low excess air region towards the region where little or no CO is produced. This is a much smaller region, yielding an average efficiency that is significantly higher than could previously be realized.

CO Control. CombustionOpt was also used to manipulate the key variables affecting CO production in the low- O_2 operating regions. (An example of this includes the auxiliary air damper biases, which affect the combustion in the burners to produce minimum CO). As CombustionOpt learned more about CO production, the process was able to be operated in such a way that CO production itself was more tightly controlled.

Stage 1 Results

Big Cajun II and NeuCo jointly conducted a series of plant tests to demonstrate the effectiveness of the optimization system. Overall, CombustionOpt increased efficiency by over 0.5%. In most of the tests, CO was not produced, indicating that further efficiency gains were likely as the commissioning continued and the operations staff became more familiar with the program. CombustionOpt simultaneously reduced NOx emissions by an average of 15%.

Table 1 quantifies the initial annual financial benefits realized by Big Cajun II.

Table 1. Heat Rate Improvement and NOx Reduction at Cajun

Unit	Unit 1	Unit 2
Net Capacity (MW)	575	575
Capacity Factor	65%	65%
Annual Output (MWh/yr)	3,274,050	3,274,050
Heat Rate Improvement (%)	0.50%	0.50%
Annual Fuel Savings	$245,799	$245,799
Average NOx Reduction	15%	15%
NOx Credit Value ($/ton)	$1,000	$1,000
NOx Reduction Value ($/yr)	$799,277	$799,277
Total Benefits ($/yr)	**$1,045,077**	**$1,045,077**

The initial CombustionOpt installations at Units 1 and 2 also provided the operations staff with a number of key insights into the plant operations. For example, the Reheat

and Superheat proportioning dampers were shown to have a significant impact on the O_2 measurements at the rear of the furnace. This is likely due to the stratification of gas flow within the ductwork and the location of the O_2 sensors. This discovery, combined with the ability to minimize variance and more tightly control O_2 within the furnace, meant that Unit 1 could be operated at lower O_2 levels than previously thought safe.

Stage I Conclusions

Even with its state-of-the-art control system and focused engineering efforts to obtain the best performance at Big Cajun II Units 1 and 2, substantial additional operational improvements were achieved through the use of combustion optimization. CombustionOpt's inductive models were based entirely upon plant data, directly relating key performance measurements to the major variables available to the operators. The system used these models to continually push the plant performance envelope while observing important equipment and safety constraints.

III. STAGE 2: COMBUSTION OPTIMIZATION EXPANSION

The staff at Big Cajun II maintained high utilization of the CombustionOpt systems installed at Units 1 and 2 and achieved sustained benefits. As the plant's needs increased over time, they expanded the scope of the optimization initiative with the following efforts:

- Adding new manipulated variables available via the addition of new NOx control hardware installed at Units 1 and 2; and
- Installing CombustionOpt at Big Cajun II Unit 3.

Incorporation of additional NOx control equipment at Units 1 and 2

In order to meet the more stringent NOx requirements facing the plant due to the Baton Rouge area being designated a Clean Air Act Ozone Non-Attainment Zone, Big Cajun II installed additional NOx control hardware on Units 1 and 2, including low NOx burners and over-fire air ports and dampers. One of the benefits of optimization software is its flexibility to respond to changing objectives and constraints and the addition of new equipment. NeuCo was therefore able to incorporate the relevant feedback from this equipment into the models' input space. In addition, the CombustionOpt system was configured to leverage new O_2 probes to help improve overall air stratification across the boiler.

CombustionOpt at Big Cajun II Unit 3

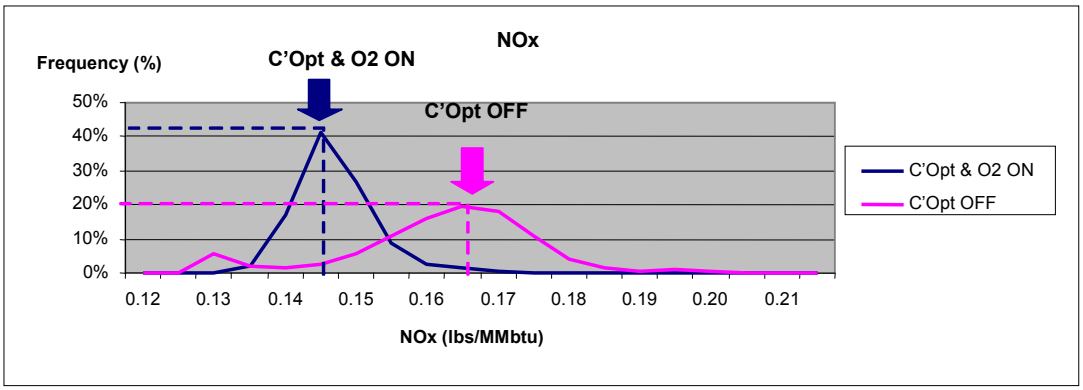
CombustionOpt was added to Big Cajun II Unit 3, a 600 MW B&W opposed-fired pulverized coal unit, in early 2003 after low-NOx burners had been installed with automated secondary air dampers made available for optimization. The objectives for the Unit 3 installation were similar to those for Units 1 and 2 at the time, with a first priority

on NOx reduction and additional objectives for heat rate improvement and CO control. Like Units 1 and 2, Unit 3 also has a Foxboro I/A DCS.

The results from CombustionOpt at Unit 3 included an average 9-11% NOx reduction and a 0.3%-0.8% heat rate improvement, both depending on the load ranges analyzed.

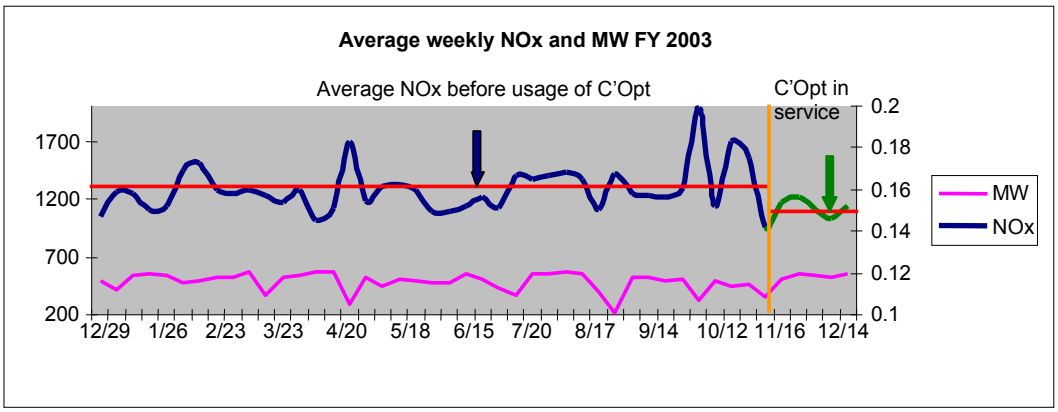
NOx Impacts. The NOx reduction benefits can be clearly seen in the frequency distribution shown in Figure 1.

Figure 1. Frequency Distribution for Unit 3 NOx On vs. Off



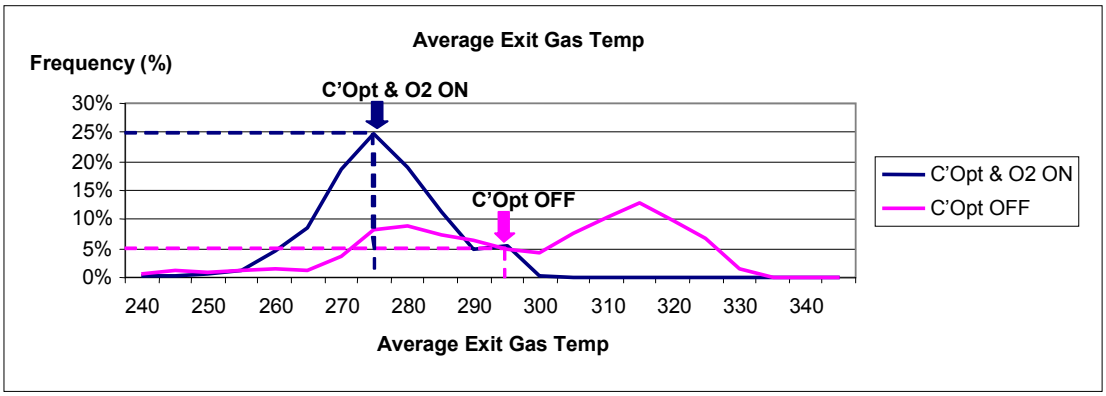
CombustionOpt's impact on NOx can also be seen from a time-series perspective, as shown in Figure 2.

Figure 2. Unit 3 NOx Pre- and Post-CombustionOpt



Details on Heat Rate Impacts. While actual heat rate values are proprietary to NRG, the underlying frequency distribution was affected in a manner similar to that for NOx, with both a reduction in the average heat rate with CombustionOpt on vs. off, as well as its variability. While we cannot show a frequency distribution of heat rate per se, the impact of CombustionOpt on average exit gas temperature shown in Figure 3 below indicates one important mechanism through which the heat rate reductions resulting were achieved.

Figure 3. Frequency Distribution for Unit 3 NOx On vs. Off



Stack gas temperature, in other words the amount of heat not transferred in making steam and leaving the stack, is one key component in determining boiler efficiency and its resulting impacts on heat rate.

CombustionOpt was also able to adhere to CO constraints while achieving the above-described reductions in NOx and heat rate, and in fact CO was on average 12% lower with the system on vs. off.

IV. STAGE 3: REAL-TIME PERFORMANCE MANAGEMENT & COMBUSTION OPTIMIZATION UPGRADES

Most recently, Big Cajun II decided to install PerformanceOpt®, NeuCo's real-time performance management system. The goal is to further improve heat rate and to enhance combustion performance by informing CombustionOpt of PerformanceOpt's real-time calculations of coal quality and boiler cleanliness. Big Cajun is also upgrading to the most recent version of CombustionOpt.

Addition of a real-time performance management system

Based on the sustained success with CombustionOpt at all three units and ongoing pressures to improve efficiency and availability, NRG Big Cajun II decided to upgrade its older-model Black & Veatch OPM performance monitoring system with NeuCo's PerformanceOpt system. PerformanceOpt is a real-time predictive performance management system that identifies efficiency and capacity losses and their impacts and enables users to take actions to control those losses and reduce operating costs. Leveraging Black & Veatch's performance monitoring experience and NeuCo's optimization software expertise, PerformanceOpt extends the capabilities of traditional performance monitoring systems by providing functionality such as real-time management of controllable losses, a single online monitoring and predictive simulation model that identifies accurate performance targets and impacts, and advanced data management technology.

BC II's goals for adopting PerformanceOpt included:

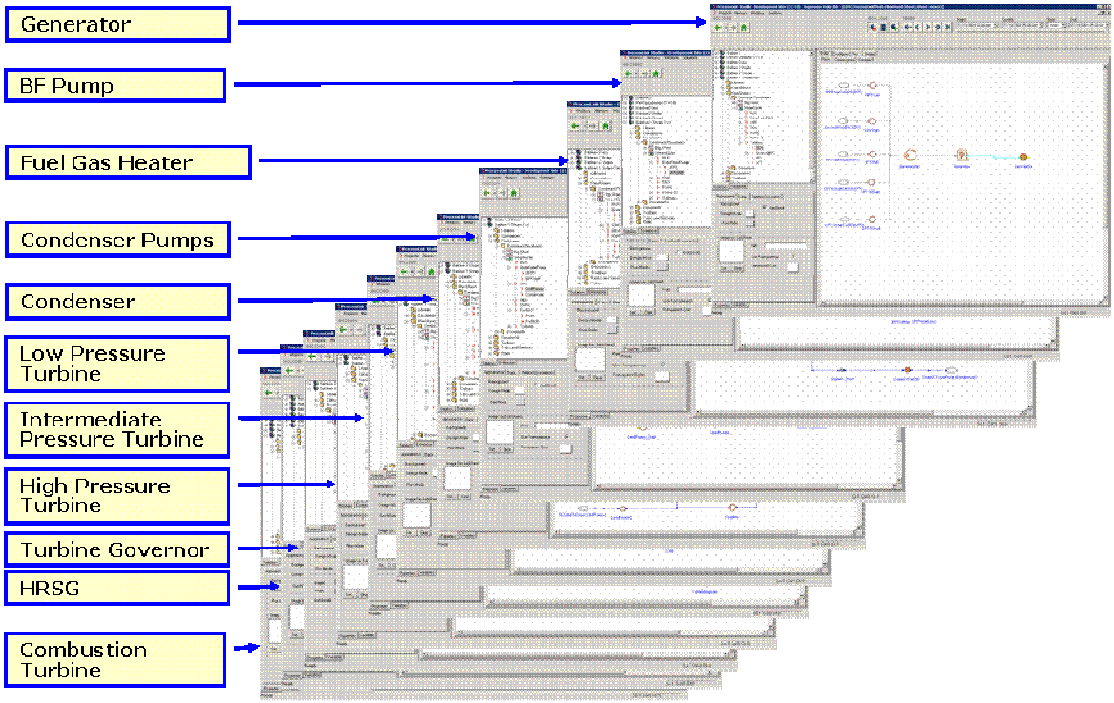
- To improve efficiency and availability;
- To improve performance and reliability;
- To provide real-time actionable data management; and
- To leverage its integration with and ability to inform CombustionOpt with better real-time knowledge regarding boiler efficiency, heat rate, boiler cleanliness, and coal quality.

Based on a detailed first-principles model of the unit, PerformanceOpt conducts a full mass and energy balance, calculating on a minute-by-minute basis the accuracy results for thousands of variables including process flow rates and conditions, heat transfer rates and sub-system and unit performance metrics. By continuously monitoring key equipment- and unit-level performance factors in real-time, the system alerts the user when actual performance deviates from what is achievable under current operating conditions. The achievable values are predicted through multiple what-if scenarios that are run with the full-scale model of the unit.

For each of the problems PerformanceOpt identifies, the system uses its predictive simulations to determine the potential improvement in efficiency and capacity that would result from resolving that problem. It then identifies and advises actions to alleviate the problem or recommends the problem for further investigation. PerformanceOpt ensures model accuracy and reliability by making use of sophisticated sensor validation mechanisms as well as equipment out-of-service logic.

The first principles PerformanceOpt model of the combined cycle process is comprised of several interconnected flowsheets that represent the totality of plant equipment, their interconnecting streams, instrumentation, source streams and products (see Figure 4). This is the rigorous model used for both monitoring and predicting performance.

Figure 4: Typical Set of modular flowsheets representing a PerformanceOpt model



While planned for all three units, the first installation is now underway at Unit 1, being undertaken simultaneously with upgrading CombustionOpt to the latest version (described in the following section). As this paper is being prepared, data collection is underway, to be followed by the boiler and turbine model configurations, and then the model integration. Further updates will be provided during the Power-Gen 2007 presentation.

CombustionOpt Upgrades

As an early adopter of combustion optimization technology in 1999, Big Cajun II has provided regular input over the years to help shape the evolution of the technology. To reflect customer input and technology advances, NeuCo issued a major new release of its CombustionOpt system in 2006 and Big Cajun II began the optimizer upgrade on its three units in 2007.

Driving forces behind the upgrade included:

- **Gain further insight into optimizer actions:** One of the shortfalls of closed loop optimization systems has been a lack of visibility into the Optimizer's actions and reasons for the actions. The new version of CombustionOpt has a Demystifier tool which shows users exactly what instructions the Optimizer has been given and how it is carrying them out (i.e. what manipulated variables (MVs) were most recently moved by CombustionOpt, and how much each MV was moved) so that users can

be confident about the actions being taken even if they at first seem counter-intuitive. Optimizers work on difficult problems and often make trade-offs to balance competing goals under tight constraints. The Demystifier provides insight into how the Optimizer is doing this, and reflects both what it has been told it to do and the process being optimized.

- **Better understand and affect actual versus achievable performance:** Big Cajun II has learned that getting the most out of an optimization system requires an understanding of how the Optimizer is performing compared to how it could be performing. The latest version of CombustionOpt provides users with a real-time view of the performance improvements being obtained. It has a variety of benchmarking approaches available with which to evaluate those improvements. It also provides advice about actions to further optimize the unit that it cannot take directly, but that if taken by the user can help deliver more benefit.
- **Take advantage of the integration between PerformanceOpt and CombustionOpt**: The CombustionOpt upgrade enables PerformanceOpt and CombustionOpt to work more closely together as they both run on NeuCo's latest ProcessLink® technology platform which enables them to share knowledge and coordinate actions and advice. The Big Cajun team believes that additional value will be achieved by having PerformanceOpt provide CombustionOpt with real-time knowledge regarding boiler efficiency, heat rate, boiler cleanliness, and coal quality.

The CombustionOpt upgrades are currently underway at Big Cajun II. The installations will be finalized and further detail will be provided during the Power-Gen 2007 presentation.

V. CONCLUSIONS

Big Cajun II has always had an innovative plant culture and been open to adoption of emerging technologies with the potential to improve plant operational and financial performance. Being a very early adopter of NeuCo's combustion optimization system in 1999 certainly had its potential risks, with the entire category of combustion optimization at that time in its infancy. But typically some risk is required to reap rewards, and Big Cajun II has obtained substantial rewards continuously in the form of improved heat rate, reduced NOx, better utilization of NOx hardware retrofits, and better overall operational performance since the time the original systems were installed through the present.

Based on this success, Big Cajun II is now upgrading its CombustionOpt systems to take advantage of the greater visibility and enhanced functionality in the latest version and is adding NeuCo's PerformanceOpt to build further on the efficiency gains obtained from CombustionOpt, leverage the integration between these solutions, and maximize Big Cajun II's commercial availability and its impact on NRG's overall financial performance.

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