SCR Control Strategy and CEMS for an Ultra-Low NO\textsubscript{x} Emitter

Dale P. Evely, P.E.  
Consulting Engineer  
Instrumentation and Control  
Southern Company Generation  
Birmingham, Alabama  35203

Harrison B. Manning  
Senior Engineer  
Instrumentation and Control  
Southern Company Generation  
Birmingham, Alabama  35203

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ABSTRACT
The Barry 6 combined cycle unit located just north of Mobile, Alabama is the first of a number of 2-on-1 natural gas fired combined cycle generating units being constructed by Southern Company for service in the new century. This 540 megawatt (nominal) unit is a first of its kind for Southern Company in a number of ways with the most notable being its ultra-low compliance limit of 0.013 lbs/mmBtu of NO\textsubscript{x}. This limit translates into 3.5 parts per million at the exhaust stack. The control of the Selective Catalytic Reduction system (SCR) ammonia feed to stay below this limit and the measurement of this ultra-low NO\textsubscript{x} level on a continuous basis each provided their own challenges. This paper will describe the SCR ammonia flow control strategy as well as the dilution extractive Continuous Emission Monitoring System (CEMS) arrived at for this project. It is hoped that this paper will assist those who are beginning to, or will one day, walk down this same path.

INTRODUCTION
Southern Company owns and operates a large number of combustion turbine based electric generating units in various parts of the world. Some of these existing units include heat recovery steam generators for combined cycle and/or cogeneration applications. The Barry 6 combined cycle unit that is currently being constructed just north of Mobile, Alabama is the first of a number of 2-on-1 natural gas fired combined cycle generating units that will utilize F-class combustion turbines. These combustion turbines (CTs) are much larger than any that Southern Company has used before and are also the first to utilize advanced dry low NO\textsubscript{x} technology in their firing systems along with Selective Catalytic Reduction systems (SCRs) to achieve ultra-low NO\textsubscript{x} emissions. There are many things that could be discussed about this facility but this paper will concentrate on the Continuous Emission Monitoring System (CEMS) for this unit and how that system is utilized as a part of the SCR ammonia feed control. It is hoped that this discussion will aid those who are facing similar challenges on similar projects.
BACKGROUND

Barry Steam Plant in Bucks, Alabama is owned and operated by Alabama Power Company, a Southern Company. Before the installation of the combined cycle unit the plant consisted of five coal-fired steam electric generating units with a total capacity of 1,525 megawatts (nominal).

Barry 6 is a 540 megawatt (nominal) combined cycle unit that consists of two General Electric 7FA combustion turbine-generators, each with a 170 megawatt (nominal) rating, and one General Electric tandem compound reheat steam turbine-generator with a 200 megawatt (nominal) rating. The Heat Recovery Steam Generators (HRSGs) for this project are triple pressure Vogt-NEM units. The three (nominal) pressure levels associated with the HRSG are 1800 PSIG, 450 PSIG, and 45 PSIG. The HRSG scope of supply for each CT includes a 3-element 181 mmBtu/hr Coen duct burner, a Babcock-Hitachi SCR, and a 121 foot tall exhaust stack. The combustion turbines and the duct burners are designed to fire natural gas only and the air permit limits the stack outlet NO\textsubscript{x} to 0.013 lbs/mmBtu during normal operation. This limit is equivalent to 3.5 parts per million (PPM) of NO\textsubscript{x} at the exhaust stack outlet. Combustion turbine exhaust, above the 50 percent CT load point, is expected to be 9 PPM of NO\textsubscript{x} or less. Each duct burner is limited to operation when its associated CT is at full load and the duct burner outlet exhaust is expected to be 12 PPM of NO\textsubscript{x} or less. Barry 6 does not utilize exhaust bypass stacks and for that reason a CT cannot be operated without passing exhaust gases through the HRSG and the SCR. Commercial operation of the Barry 6 combined cycle unit is scheduled for May of 2000.

The combustion turbines and the steam turbine utilize GE Mark V control systems for their basic control and sequencing. HRSG and balance of plant controls, including the SCR, were implemented by Southern Company using Westinghouse Ovation digital control system hardware and software. CEMS hardware and software were provided and integrated by Spectrum Systems, Inc. of Pensacola, Florida. The CEMS is designed to collect and report data in compliance with 40CFR75 requirements.

CEMS RELATED CHALLENGES

The Barry 6 project brings with it the need to measure NO\textsubscript{x} in the 3.5 PPM and lower range, which is well below the majority of the experience base to-date. Another complication is that the selected SCR technology includes ammonia injection and some of this ammonia makes it all of the way through the SCR. Ammonia levels in the exhaust stack will probably range from 0 to 10 PPM. This means that we will need to measure NO\textsubscript{x} in the presence of comparable levels of ammonia, which can cause problems for some NO\textsubscript{x} measurement techniques. Also, because of the dynamics of the advanced dry low NO\textsubscript{x} combustion process, a high percentage of the NO\textsubscript{x} will be NO\textsubscript{2}. Sulfur dioxide will also be present in the flue gas but only in very small quantities since our fuel is natural gas.

During the early stages of planning for this project a total of three existing facilities were identified that were in operation with an equivalent 4.5 PPM permitted NO\textsubscript{x} limit. Only one existing facility was identified with an equivalent 3.5 PPM permitted NO\textsubscript{x} limit. All four of these facilities utilized ammonia based SCR’s to achieve these low NO\textsubscript{x} limits. All four of these facilities were contacted but two of them, including the one with the lower limit, would not provide information on their monitoring
systems, apparently for competitive reasons. A minimum amount of information about these two facilities was gleaned from the public record. The other two facilities were essentially identical and were very forthcoming about their monitoring experiences.

At least three of these four facilities utilized full extractive chemiluminescence based NOx analyzers and paramagnetic type oxygen analyzers. The public record for one of these facilities listed sixteen different missing data periods due to sample transport system failures and seven other periods that may have also been a result of this type of a problem. The two facilities that were willing to share information with us stated that they did have some minor problems with their sampling system at times but for the most part their systems were working satisfactorily. All of the facilities seemed to have more than a few problems with working the bugs out of their Data Acquisition and Handling Systems (DAHSs).

CEMS REQUIREMENTS

It was determined, by the team charged with defining a monitoring system for this site, that the most desirable CEMS installation would meet the following general requirements:

- High reliability
- Low maintenance
- Relative accuracy consistently less than 5%
- Equipment similar to our existing CEMS installed base to maximize our use of existing spare parts and training
- Software essentially the same as our existing CEMS installed base to allow reports and data files to be generated in a consistent manner and to allow seamless integration with our existing data systems

It was further determined that due to our previous CEMS experience and the experiences of others in the power generation industry the CEMS should meet the following specific requirements:

- Materials shall not be used that are subject to degradation by ammonia (i.e. Viton, etc.).
- The sampling and analyzer system shall be designed to minimize any ammonia interference with the NOx measurement.
- The use of materials that could act as a NOx/ammonia catalyst shall be minimized to the greatest extent practical to ensure an accurate reading at the NOx analyzer.
- The gas sampling system shall be designed to prevent corrosion, plugging, as well as any accumulation of water that could result in a restriction in sample flow.
- Any required NO2 to NO converter shall be optimized to prevent interference from ammonia.

CEMS DETAILS

Measuring NOx at ultra low levels in the presence of similar levels of ammonia is new territory for most CEMS vendors. Most vendors recognize that there are problems associated with this measurement although the problems are somewhat mitigated when a natural gas fired unit is involved. Southern
Company has had excellent performance from dilution extractive based chemiluminescence NO\textsubscript{x} analyzers and this is the technology that was selected for use on Barry 6. It is expected that a dilution system will minimize ammonia/sulfur/moisture related problems in the sampling system. The dilution system does have problems, however, measuring NO\textsubscript{x} on an oxygen basis so CO\textsubscript{2} is also measured as the diluent and an oxygen based NO\textsubscript{x} number is then mathematically calculated. This approach has been acceptable to regulators on other projects.

The CEMS for Barry 6 measures natural gas fuel flow, stack NO\textsubscript{x}, stack ammonia, and sample system CO\textsubscript{2}. The natural gas flow is needed for compliance reasons as are the NO\textsubscript{x} and CO\textsubscript{2} measurements. The natural gas flow is used to calculate stack SO\textsubscript{2}, stack CO\textsubscript{2}, heat input, and SCR inlet NO\textsubscript{x}. Stack ammonia is not being measured for compliance purposes and it is still uncertain if stack ammonia can be measured reliably. If stack ammonia can be measured reliably it will provide valuable information on SCR performance.

The SCR inlet NO\textsubscript{x} will be calculated based on the natural gas flow to both the combustion turbine and the HRSG duct burner. This calculation will be based upon manual testing that will be performed during unit start-up. It would be difficult to measure SCR inlet NO\textsubscript{x} directly on a continuous basis because a multi-point sampling grid would be required due to gas circumferential stratification typical with a combustion turbine firing system. The initial stages of the HRSG may help to mitigate this stratification but the cross sectional area at this location is quite large and a reliable measurement would be difficult to obtain without multi-point sampling. SCR inlet NO\textsubscript{x} is needed as a feedforward for the ammonia injection system and will also provide valuable information on the overall combustion system and SCR performance over time.

The dilution probe associated with the NO\textsubscript{x} monitoring system is a heated M&C ex-situ dilution probe mounted on the side of the exhaust stack. Close coupled to this dilution probe, also mounted on the stack, is an ammonia converter. The ammonia converter takes the sample stream from the dilution probe and splits it into three separate streams. One of these streams is called the NO stream and it is passed through unchanged. The second stream passes through an ammonia scrubber. The third stream passes through a converter that converts all of the ammonia in that sample stream to NO. These three sample streams are sent through a heated umbilical line to the CEMS shelter that is installed at the base of the exhaust stack.

Diluting the flue gas sample and then quickly converting or removing the ammonia present in that sample should prevent interference of the ammonia with our NO\textsubscript{x} measurement. The first sample stream has the ammonia scrubbed from it when it reaches the CEMS shelter and it then passes through a TECO chemiluminescense NO\textsubscript{x} analyzer. Since this analyzer can actually see only NO, it measures the amount of NO present in the sample. The second sample stream has already been scrubbed for ammonia and when it reaches the CEMS shelter it passes through an NO\textsubscript{2} to NO converter. This second sample stream is then used to measure total NO\textsubscript{x}. The third sample stream passes through the analyzer and since the analyzer cannot see the NO\textsubscript{2}, its measurement is equal to the NO in the sample stream plus the ammonia. The ammonia measurement can then be made using a differential NO measurement technique by subtracting the measurement of the first stream from the third stream. The NO\textsubscript{x} analyzer in this system is manufactured by TECO and it is, of course, timeshared between the three sample streams.
It should be restated that the experience base of measuring low levels in the presence of similar levels of ammonia is new territory. Modifications to the system may be required as Barry 6 moves towards commercial operation. The system described is, however, what we believe to have the best chance of meeting the performance requirements that were identified.

**SCR CONTROL STRATEGY**

The control strategy for the ammonia feed to the SCR was initially defined by the SCR manufacturer. This strategy was expanded upon by Southern Company and implemented in the plant digital control system.

The basic concept of SCR operation is fairly simple. If the SCR catalyst is in the appropriate temperature range and if an adequate amount of ammonia is completely mixed with the flue gas then the NO\textsubscript{x} present in the flue gas will, with the help of the catalyst, combine with the ammonia to make molecular nitrogen and water vapor. If everything happens properly, the ratio of ammonia injected to NO\textsubscript{x} removed will be one molecule of ammonia for each molecule of NO\textsubscript{x}. If an inadequate amount of ammonia is injected more NO\textsubscript{x} will leave the exhaust stack than is allowed by the air permit. If too much ammonia is injected the catalyst will physically not be able to reduce an equal amount of NO\textsubscript{x} and the excess ammonia could result in ammonia salt formation and tube fin pluggage as well as excess ammonia passing out the exhaust stack. If the ammonia is not properly mixed then excess ammonia passing through the catalyst will cause similar problems as well.

A logic diagram of the SCR ammonia feed control loop appears as Figure 1 on the next page. It can be seen from this diagram that even though a signal is being developed for stack ammonia (NH\textsubscript{3}) concentration, this signal is only planned for alarm purposes. This is due to the reliability concerns associated with this signal.

The ammonia feed control loop uses a cascaded-feedforward control scheme. The lower controller in this scheme is a simple ammonia flow controller. The ammonia flow setpoint is developed by the upper controller and its feedforward signal. This setpoint is compared to the measured ammonia flow and the output, when in automatic, is adjusted accordingly. This output signal adjusts not only the ammonia flow control valve but also the dilution airflow. This dilution air is used to help transport the ammonia vapor and to assist with the mixing of that vapor with the flue gas.

The feedforward signal is generated from the calculated SCR inlet NO\textsubscript{x} and the total heat input to the CT and duct burner. This calculation is to determine the lbs/hr of ammonia flow required for the current lbs/hr flow rate of NO\textsubscript{x} into the SCR.

The upper controller of the cascaded control loop compares the stack NO\textsubscript{x} to the preset NO\textsubscript{x} setpoint and then trims the feedforward signal to adjust for any inaccuracies in the other measurements. The stack NO\textsubscript{x} signal must be assumed to be correct since it is the measurement that is used to determine compliance with the air permit limit.
If an analyzer fault is detected the ammonia flow control loop will reject to manual operation and the ammonia flow rate will need to be adjusted by the operator. While the CEMS is in an automatic calibration cycle the ammonia flow setpoint will freeze at its last value. If the SCR temperature is not above the minimum required for catalyst operation the ammonia flow control valve will be held closed and the loop will be held in manual.

Figure 1 - SCR Control Strategy Logic Diagram
PLANS FOR THE FUTURE

As was previously stated, Barry 6 commercial operation is scheduled for May of 2000. Although actual start-up experience with this unit will not be obtained until after the paper submittal deadline for this conference it was felt that there was enough interest in this subject that a paper was needed. The presentation of this paper is scheduled for early June of 2000 and at that time any changes that were necessary during start-up of the unit can be shared. Successful monitoring and operation of Barry 6 is not just important to Southern Company for the sake of Barry 6. We have three other combined cycle units identical to Barry 6 in construction for 2001 commercial operation that will rely heavily on the lessons learned from this project. We are currently also in the permitting process for similar units for 2002 commercial operation and are planning additional units for future years.

It is hoped that this paper is found useful by those who are beginning to, or will one day, walk down this same and unfamiliar path.