State of the Art Ammonia Injection Control System for SCR on Combined Cycle Power Plant

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Summary

1. Introduction

Hitachi Zosen has extensively studied the reaction kinetics of our SCR catalyst NOXNON700. The reaction rate equation of the catalyst dynamics is applicable in a steady state operation as well as an unsteady state operation, which includes the rapid change in the flue gas conditions (gas velocity, temperature NOx concentration and etc.) exhausted from a gas turbine. The future of this control system is to combine the reaction dynamics of the catalyst into the ammonia injection control system. This has been successfully applied to the SCR for combined cycle power plants since December 1998. This paper introduces Hitachi Zosen's control technologies and presents the controllability of NOx and NH3 emissions at commissioning.

2. Outline Of the Latest SCR System for combined cycle power plants

Hitachi Zosen's NOXNON700 honeycomb type catalyst, which was developed in 1987, has been successfully and widely supplied to SCR units for large and small-scale commercial power plants and thermal furnaces. NOx in the flue gas reacts selectively at the catalyst with ammonia, which is injected into the flue gas, and N2 and H2O are generated as products of the De-NOx reaction. The liquid Ammonia is stored in an ammonia storage tank, evaporated and then the ammonia gas is injected into the flue gas through the ammonia injection grid (AIG) after being diluted with air.

The gas flow rate, temperature and NOx concentration exhausted from the gas turbine changes rapidly during the turbine's operation, which includes normal start up, loading and shutdown. In the gas turbine combustor (DLN1) supplied by General Electric, NOx concentration changes from 9.4ppmvd to 60.2ppmvd during the Primary mode, to 49.0ppmvd to 90.0ppmvd in the Lean Lean mode.

We were requested to be at a 3.57Nm3/H or less per hour rolling average of NOx at the HRSG outlet from firing to base load. As well as 6.0ppmvd (@O2 16%) or less out of the Premix mode after synchronizing, and 1.6ppmvd (@O2 16%) or less of NOx and NH3 at the HRSG outlet in the Premix steady state mode which includes the base load of 165 MW.

In the conventional ammonia injection control system, the mole ratio control is applied. This determines the ammonia injection flow rate by multiplying the NOx mass flow signal (usually we use this to predict the NOx flow rate at the gas turbine outlet) by the required mole ratio. However, it is difficult for this control method to improve the control characteristic in an unsteady state, like at start up, shutdown, or sudden roll changes since the reaction kinetics of a SCR catalyst are not considered.

3.Design of the ammonia injection control system

Summarized below are technical issues that arise regarding the ammonia injection control and the techniques used to solve them.

(Issue - 1) Dead time in NOx concentration sensing

The dead time of the NOx analyzer and the sampling line at the HRSG outlet was 52.6sec. and the time constant was 20.0sec. (for a 90% response) in our measurements. Therefore, during an unsteady state operation like startup and shutdown, the NOx concentration at the HRSG outlet is only controlled by the feed forward controller without the feed back controller. However, during steady state operation, a combination of the feed forward and the feed back controller maintain this.

(Issue - 2) Non linearity of De-NOx reaction

We designed the feed forward controller based on the reaction kinetics of NOXNON700.

(Issue - 3) Catalyst Deterioration

Catalyst performance reduction due to its' deterioration is compensated during the steady state because the NOx at the HRSG outlet is maintained by both the feed forward and feed back controllers.

(Issue - 4) Deviation between predicted and real NOx concentration in exhausted gas

We designed the algorithm to adjust the predicted NOx concentration to the measured one.

(Issue - 5) Changes of NOx emission due to GT load changes

During an unsteady state operation like startup and shutdown, NOx concentration at the HRSG outlet is controlled by the feed forward controller without the feed back controller.

The reaction kinetics of NOXNON700

(1) The NH_3 adsorption rate onto the catalyst surface is proportionate to the NH_3 concentration on the catalyst geometric surface and the number of active sites on the catalyst for NH_3 adsorption.

(2) The NOx reduction rate is proportionate to the NOx concentration on the catalyst geometric surface and to the quantity of NH_3 adsorbed onto the catalyst.

(3) NH_3 de-adsorption rate from the catalyst surface is proportionate to the quantity of NH_3 adsorption.

(4) NH_3 oxidation reaction is confirmed to be a preliminary reaction.

These chemical mechanisms, the effect of the boundary mass transfer on catalyst and the material balance of NOx and NH_3 in the flue gas, establish the reaction rate equations.

Feed forward controller

The feed forward controller inputs the target value of NOx concentration at the HRSG outlet and the flue gas conditions at the inlet to the catalyst (gas flow rate, temperature and NOx concentration). Based on the reaction kinetics of NOXNON700, the controller calculates the required quantity of NH_3 adsorption to make the NOx concentration at the HRSG outlet meet the target value and then determines the ammonia injection flow rate.

Feed back controller

During steady state operation, NOx concentration at the HRSG outlet is controlled by a combination of the feed forward and the feed back controller which compensates for any errors made by the feed forward controller. The NOx analyzer and its sampling line at the HRSG outlet have usually a long time constant and dead time, so we selected the sample PI controller. The controller has variable gains, which are described as the inverse process gain (De-NOx rate variation / mole ratio variation) which is calculated by the flue gas conditions (flue gas flow, temperature and NOx at the GT outlet) and the set value of NOx concentration at HRSG outlet.

Modification of the predicted NOx concentration

In our measurements, the dead time and the time constant of the NOx analyzer including the sampling line at the GT outlet were 23.4sec. and 21.0sec.(for a 90% response) respectively. Therefore, the signal from the NOx analyzer can not be directly used to control the ammonia injection flow rate because the changes of NOx emission due to the gas turbine load changes are very rapid.

In the conventional method of ammonia injection control, the controller determines the amount of ammonia, by using the predicted NOx flow rate signal (calculated value). But this signal has some deviation between the predicted and the real NOx concentrations in the flue gas exhausted from the GT. Therefore, we designed the algorithm to modify the predicted NOx concentration by comparing the predicted NOx, which includes the response of NOx analyzer, with the measured NOx concentration.

4 Experimental results of ammonia injection control

The rate constants, which are the parameters of the controller, were obtained by laboratory scale experiments. We finely tuned them by evaluating the control results at the commissioning. From GT firing to base load, the maximum of one hour rolling average of NOx at the HRSG outlet was 3.3Nm3/H. After synchronizing, the NOx concentration at the HRSG outlet was less than 6ppmvd (@O2 16%) during every combustion mode. Both NOx and NH3 at the HRSG outlet were controlled at 1.6ppmvd(@O2 16%) or less during steady state operation in the premix mode which included the base load of 165MW. We were able to confirm that all the required performances were met.

5.Conclusion

Hitachi Zosen has designed the new ammonia injection control system of SCR for combined cycle power plants in consideration of the reaction dynamics of our NOXNON700 catalyst. As a result of performance tests at commissioning, we verified that we meet all the required NOx and NH3 emissions at the HRSG outlet during GT firing to a base load of 165MW. This system has been successfully operating since December 1998.